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U. S. DEPARTMENT OF AGRICULTURE,

DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY.

ALBERT F. WOODS, Chief.

PLANT BREEDING.

BY

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U. S. DEPARTMENT OF AGRICULTURE,
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Washington, D. C., January 28, 1901.

SIR: I have the honor to transmit herewith the manuscript of a paper on plant breeding, prepared by Prof. Willet M. Hays, of the University of Minnesota. Professor Hays has been engaged in plant breeding for a number of years and has done much to arouse an interest in the subject throughout the country. The Department of Agriculture, through its laboratory of plant breeding, several years ago actively took up the investigation of plant-breeding problems, and much work has been done in the improvement of cotton, corn, wheat, oranges, pears, grapes, etc. Results of great importance have already been obtained, and several papers treating of important factors of plant breeding have been published in bulletins of this Division and in the various Yearbooks of the Department of Agriculture since 1897. The present paper is of special interest to experiment station workers and others engaged in similar lines, and I respectfully recommend its publication as Bulletin No. 29 of this Division.

Respectfully,
ALBERT F. WOODS,
Chief of Division.

HON. JAMES WILSON,
Secretary of Agriculture.

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PLANT BREEDING.

INTRODUCTION.

Much scientific thought has been centered on fertilizing the soil that the largest possible returns might be secured from a given amount of labor and expense. Man has been slow to recognize that plant life is in a wonderful manner subject to his control. There has been a controlling philosophy connected with botanical thought which has held too closely to the doctrine of the immutability of species in plants. The systematic botanist held the species so close to our eyes that the mobile character of the plants was not generally recognized. That "like begets like" is an important fact; but it is of greatest importance when used to intensify or fix variations of peculiar merit that these variations may be multiplied and thus become the basis of improved varieties. The results of breeding and the science of breeding have come forward slowly and unobtrusively. Their significance has not been fully appreciated. In view of the great results from breeding which have already appeared, it is safe to assume that persistent systematic effort will bring improvements that are now generally deemed impossible.

In any country there are very many localities each with its special conditions and needs. Each locality uses not a few, but many, species and varieties of plants, each suited to the particular soil, climate, and other conditions. Now that the creative work of plant breeding has been taken up by many scientific workers in State experiment stations, the national Department of Agriculture, and by many seed firms and individuals, variety formation and scientific breeding are bound to develop very rapidly. The suggestive work of Charles Darwin is at last vivifying the dormant ideas concerning breed and variety formation. Weismann and others who study heredity will continue to be heard with interest; and those who are studying methods of plant breeding to increase production will be heard in proportion to the economic and artistic value of their products and to the scientific value of their theoretical discoveries. Many of the facts relating to heredity are not only of great interest but of great value to the breeder. The study of the cell and of embryology is adding knowledge of exceedingly great value to the breeder. The known facts of animal and plant breeding, largely wrought out in extensive practice, and the visible results of the work of those who breed plants and animals, are for the present of paramount economic importance. They give the basis for a most valuable philosophy, because simple and useful. Plant breeding in America is very much underdone, and in many of its lines public money invested in experimental work may be made to yield to the country a hundred or a thousandfold. The literature of the subject of plant and animal breeding has not been as hopeful in tone as the achievements and the great importance of the subject have warranted.

The knowledge of the subject of breeding has not been well classified, nor has it been properly emphasized. There are a few books, many scattered articles, and numerous statements in the general writings of many men. Charles Darwin, in his work on "Variations of animals and plants under domestication," and other writings, brought together a large collection of facts and a most original philosophy of heredity and variation. He recognizes the force of facts shown by improvements which men had achieved in breeding plants and animals. J. H. Wallace, in Volume II of Wallace's American Trotting Register, and in other writings; J. H. Sanders, in his book on Horse Breeding; Manly Miles, in Stock Breeding; and other American writers on animal breeding, have shown that they in part comprehend the force of Darwin's philosophy as relates to animal and plant breeding. Prof. L. H. Bailey and other recent writers have done much to arouse an interest in breeding plants. The plant improvements of most marked prominence are recent, and the men who have done the best work have written but little. They have worked with plants rather than with the written theories. The theory of many writers gives less encouragement for far-reaching results than the facts warrant. The long time required to produce considerable changes in the species and varieties of useful plants has had a very retarding effect upon progress in this line of work. Results of immense economic importance which have already been attained should be shown in their true light. Where the individual can not afford to wait for results and will therefore not properly carry forward variety formation, it is the duty of the State to assume the work. The length of time required to breed special varieties of each class of economic plants suited to each locality should not, henceforth, prevent the expending of much effort in this direction.

Besides being a subject of vast economic importance, the breeding of plants is a fascinating study and a most enchanting pastime. It is one of those subjects in which students like to specialize. Students in the writer's college classes, as soon as they gain a place to work in the field-crop nursery and seed house, wish to forego specializing in other subjects and concentrate their energies on this fascinating and productive work. In looking toward the future, it seems probable that plant breeding will receive far more attention than heretofore. In European countries much more attention is given to the improvement of plants than in America. In two towns in Germany there are nearly 30 large seed firms, with an aggregate capital investment probably five times as great as the capital of the general seed firms of America. In that country owners of large farms breed and raise seeds of wheat, oats, rye, sugar beets, potatoes, and other crops. They get better profits from this work, and they build on their farms chemical and seed laboratories where the seed selection is done systematically. Those farmers to whom they supply seed which will make their yields larger are also benefited.

In England, the average yield of wheat is over 30 bushels per acre, while in the United States it is below 15 bushels. This difference is in part due to the better preparation of soil and the moister climate; but doubtless it is also due in part to the selection and breeding of wheat during a much longer period than has passed since wheat was first grown in this new country.

Dr. Rimpau, Mr. Haine, Mr. Strube, and other farmers of Germany, which country I had the pleasure of visiting recently, find that seed growing and breeding is a very practical vocation. They breed wheat in a manner somewhat similar to the plan described in the following pages, and they employ system and precision in the selection of individual plants and of resulting varieties. Mr. L. H. Haynes, of Fargo, N. Dak., has done much careful work in breeding wheat, and has made greater profits from his farm than if he had raised the standard varieties of wheat for the market.

Breeding plants, since the literature on the subject is growing in volume, gives opportunity for wide study. Especially as an art does the breeding of plants give the opportunity for the development of skill of a high order. The breeders of plants, as well as the breeders of animals, need to make more of a study of records, of relationships; in a word, design, collect, and study pedigrees of the plants and animals with which they deal.

In many cases amateurs who have followed up accidental forms of value have sold them to dealers at good prices, and some amateurs breed plants according to a carefully considered system, making a profit for themselves and at the same time producing valuable varieties for cultivation. Bright young farmers can not undertake work which is better calculated to add interest to their chosen business than to become breeders of pedigree plants or animals. Seedsmen depend largely upon amateurs for new and valuable varieties, and they are always ready to pay good prices for useful new sorts. The seedsmen of America have not kept pace with European seed firms in variety formation, nor even in keeping up and improving old forms. They have here a most legitimate field; unless they develop this feature, they remain only seed merchants, and can hardly hope to gain that position in the minds of purchasers which they should hold to have the most profitable seed trade.

Plant breeders need not work along narrow lines nor follow set rules. There are many ways of conforming to the broadly applicable principles of producing, finding or discerning, fixing, and multiplying desirable variations. The devices of each plant breeder will solve the problem for his environment and for the objects he seeks. Plans outlined to suit the needs of one may not wholly meet the requirements of another situated differently.

The great system of American experiment stations has fairly begun the work of variety formation in important plants. We can, therefore, hope for the subject to be gradually placed upon a thoroughly scientific basis. There is room and need in this line of work for the best energies of all the agencies, amateurs, seed growers, seed firms, and experiment stations, including that largest one, the national Department of Agriculture.

The writer is under obligation to Mr. Andrew Boss, assistant in agriculture in the University of Minnesota, and to others who have assisted in the experiments (as yet not all reported in station bulletins) upon which this paper is in part based; also to student assistants who have aided in preparing the illustrations.

GENERAL OBSERVATIONS ON PLANT BREEDING.

RELATION OF PLANT BREEDING TO WEALTH.

The economic results from plant improvement are already enormous in the aggregate, and the possibilities for the future are so great as to be truly dazzling. Circular No. 11, recently issued by the Division of Statistics of the U. S. Department of Agriculture, for example, estimates the world's wheat product for 1899 at over 2,500,000,000 bushels. Assuming the yield to be 20 bushels per acre, this required 125,000,000 acres of land. In ten years the Minnesota station, by careful breeding, produced a new variety of wheat, which yielded nearly 25 per cent more grain on the university farm than its parent variety, which was the best variety generally grown in the State. The following table (Bulletin No. 62, Minnesota State station) shows comparative yields of the new and the parent variety on several experimental farms. In the last two columns appear the average results obtained in five successive seasons at the university farm, near Minneapolis. It should be observed that this new variety has not proven so much superior in yield to the parent variety on other experimental farms a few hundred miles distant, which emphasizes the need of breeding varieties for each locality:

Minnesota No. 169 compared with its parent variety, Minnesota No. 51.

Where grown.	Season.	Yields per acre.		Yields per acre at university farm.	
		Parent variety.	New variety.	Parent variety.	New variety.
		Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
University farm	1895	21.6	37.8	21.6	37.8
Do	1896	24.6	25.0	24.6	25.0
Do	1897	20.4	24.3	20.4	24.3
Do	1898	23.3	26.3	23.3	26.3
Do	1899	25.9	28.8	25.9	28.8
Northeast farm	1898	23.0	19.3		
Do	1899	11.7	13.4		
North Dakota	1898	33.5	38.4		
South Dakota	1898	20.2	14.1		
Iowa	1898	8.8	12.5		
Average		21.3	24.0	23.2	28.5
Gain			2.7		5.3

Twenty-five per cent, or 5 bushels per acre, increase would add to the world's supply of wheat 625,000,000 bushels. This, at 80 cents per bushel, would be valued at $500,000,000 for each year. If by breeding we can increase yields only so much as 5 per cent, or 1 bushel per acre, we will still have an increase of $100,000,000 per annum, or 1,250,000,000 bushels increase in the world's crop in ten years. Since the United States produces about one-fifth of the world's wheat supply, an annual increase of 1 bushel per acre would result in ten years in an increased valuation of $200,000,000 for this country. One-tenth of 1 per cent of this sum spent in wheat breeding would doubtless be more than sufficient to produce a much greater increase than 1 bushel per acre. The writer's interpretation of the facts concerning the production of numerous new varieties of wheat in Minnesota by selection, aided by occasional hybridizing, is that 25 per cent increase in yield is a conservative estimate of what it is practicable ultimately to accomplish in that State in the improvement of wheat by breeding. Several decades will be required to accomplish this, and the proof is now nearly conclusive that breeding, or at least variety testing, must be done for each general locality within the State.

The breeding of corn in the United States has resulted in a very marked improvement of that crop. In nearly every county there are varieties or strains specially suited to local conditions. Formerly those dent varieties which yielded large crops of grain were adapted only to the Southern and Middle States. Now dent varieties are found maturing large crops nearly to the center of the northernmost tier of States. Through selection the farmers of the Northern States have greatly increased the yields of their cornfields. Corn being such a large plant that each ear is taken in the hand in husking out the crop, the farmer has been able to choose the very best yielding plants out of immense fields. Without fully recognizing the fact, the farmers of America have been conducting with corn the most extensive breeding experiment ever carried on.

Corn being an open fertilized species, large numbers of new forms have resulted from accidental hybrids between different varieties in adjacent fields, thus forming many local varieties of this very interesting plant, and building up the yield and quality of the corn crop of America.

If the corn crop of the United States were reduced to 80 per cent of its present yield we would have 1,600,000,000 instead of 2,000,000,000 bushels, or an average of 20 instead of 25 bushels per acre. What farmer would think of returning to the smaller ears of fifty or one hundred years ago? Yet it is quite possible in another half century, by more careful breeding and with greater attention to the composition and quality of our corn, to make as important improvements as have been made in the past. It is probably safe to say that the farmers, by adding 25 per cent more to the care and labor of rotating crops, manuring the soil, and cultivating the corn, could secure 25 per cent larger yields. And it is probably just as safe to say that if one-tenth of 1 per cent of the corn crop's value were devoted by the Government to breeding this plant so as to better adapt it to each locality, 10 per cent more could be added to the yield. While better farming and better cultivation are ultimately the more important in the aggregate, plant breeding is relatively more important until our crops are brought up more nearly to their possible maximum of yield.

Our ten leading field crops in the United States yield an annual income which is valued on the farm at something like $2,000,000,000. No man who has earnestly and intelligently tried to increase the yields of any one of these crops will doubt the assertion that by breeding alone, other conditions remaining the same, an average increase of 5 per cent could be added to the yields of these ten crops in twenty years by a line of thorough experimentation. Prices remaining the same, this would add $100,000,000 annually to the aggregate valuation of these crops; or, in twenty succeeding years, $2,000,000,000. If to the increase in value of our principal field crops are added the increase in values of orchard, garden, greenhouse, and forest crops, we will have a much greater aggregate gain. All these crops are capable of improvement by breeding, the same as corn and wheat, and the general principles to be followed are the same throughout. In many of the flower and vegetable crops changes have already been produced by breeding that are far greater than the anticipated changes in the yields of corn and wheat.

In the case of sugar beets, for example, the percentage of sugar in the juice of the roots has been increased probably 100 per cent by rigid scientific methods practiced on a large and expensive scale by

European seed growers. This work, started by Vilmorin of France, has made possible a large industry, profitable to the farmers and to manufacturers, and has resulted in much cheaper sugar for the entire world. Here, as in other lines of breeding, the principles and practice are comparatively simple and easily mastered. Remove it from the domain of abstruse reasoning, where some teachers of heredity place it, and plant improvement becomes a practical business proposition, an important affair of state.

EXAMPLES OF RESULTS OF BREEDING.

Three illustrations from plant breeding and from animal breeding, in which the general principles are the same, will suffice to emphasize the simpler side of the question of improving our useful plants:

THE WEALTHY APPLE.

The Wealthy apple, originated by Peter M. Gideon, of Minnesota, will serve as the first illustration. Mr. Gideon planted many apple seeds and watched the seedling trees develop. Most of the young plants succumbed to the severe Minnesota winters. One plant stood out prominently as being very hardy, and as the years passed it grew to a fruitful tree. Its fruit was fine in appearance and of superior quality. Mr. Gideon grafted some of the scions on other trees, and others he grafted on seedling roots, making independent trees. True to the nature of the apple tree, all these cuttings grew and bore fruit like that of the seedling plant. Mr. Gideon gave trees to his horticultural friends, and, being a nurseryman, sold many to his customers. This variety of apple now stands as a testimonial to Mr. Gideon's usefulness. He since has added a number of other useful hardy varieties to the apple list of the middle Northwest. The Wealthy apple, being the first prominent product of the efforts at breeding a hardy race of apples for the section of country mentioned, has a peculiar interest. As is often asserted, this apple, considered merely as a fruit product, may be worth more than a million dollars, but its value as an encouragement to apple breeding, and to plant breeding generally, is far greater. There are now being bred in Minnesota and surrounding States very many new varieties of apples from hardy parents.

THE RACE HORSE, MESSENGER.

Messenger, an imported English race horse, which became the leading progenitor of the American race of trotting horses, will serve as the second illustration. In nearly if not quite all of the best individuals of this great breed there is some of the blood of this horse, famous, not for his individual performance, but because of his power to transmit to so great a progeny the ability to win trotting races. This ability to trot is made up of many correlated elements, such as the instinct to contest the race, the form of body which permits light and free action, the texture of every bone, fiber, and nerve, and the teachable nature which enables the trainer to educate the horse. A combination of all these characteristics was given to this race of horses by the parent horse. Many other running horses have been employed in efforts to produce a competing strain of trotters. But the blood of Messenger stands above them all. And his descendants, through rigid selection extensively practiced, are gaining in trotting ability from year to year. He was a chance discovery. With the element of variation once in hand, the horsemen of America have gone on improving and intensifying it and reducing the American trotters to a uniformly fast-trotting race of animals.

MINNESOTA NO. 169 WHEAT.

One of the varieties of wheat originated by the Minnesota experiment station will serve as the third example. This wheat, mentioned on a previous page, was originated from a single plant (No. 476, of 1892) in the following manner: Several of the best plants were chosen from among 400 plants of Blue Stem, each growing separately, a foot apart each way. Each of the selected plants yielded 500 or more grains of wheat weighing 10 or more grams. The seeds from each chosen plant were planted for a few years until sufficient seed was obtained to plant a field plot. Then for several years each of the new strains was grown in a field beside the parent variety from which the 400 original seeds were chosen. A few of the new strains proved superior to the parent variety, but the one named Minnesota No. 169 stood out so preeminently superior that all others were discarded. For a large area of Minnesota this wheat seems capable of yielding at least 1 or 2 bushels per acre more grain than its parent variety, which is the best kind commonly and almost universally found on the farms in southern and central Minnesota. This variety in ten years could be increased so as to almost displace the parent wheat. The peculiar quality or power in the single germ which was the parent of plant No. 476 in our field crop nursery in 1892 had a very great value. The system which was followed to find the germ of greatest value is comparatively simple. The cost of finding this plant and of developing a variety of wheat from it, including the cost of forming and testing all the strains which failed to reach first place, was probably not one-thousandth of the value of this new wheat. The production of this and other similarly useful new varieties gives courage to experimenters, and warrants the State in investing more money in similar experimentation with wheat and other important crops.

The purpose of this paper is to show the importance of plant breeding to the country and to the farmers and gardeners, and to throw out into clear light its important practical features. The great question is, How can we get results? If a single germ has such wonderfully far-reaching power and immense value, as in the instances mentioned above, we want to know two important things: (1) How shall germs with the special values be produced? (2) How shall we select them out of the large number which must be grown to secure the superior one?

THE VALUE OF LARGE NUMBERS IN BREEDING EXPERIMENTS.

The history of breeding animals and plants has many lessons, only a portion of which are as yet read understandingly. The English breeder of hounds expressed a most important truth when answering an inquiry as to the secret of his success. He said: "I breed many and I hang many." Only the very few of highest value out of many were used as the foundation stock for further breeding. This does not mean that he did not keep many hounds in his kennels at one time. In most cases he could not determine the value of the blood of a certain sire or dam until he had numbers of his or her progeny. Not infrequently the blood of a certain animal or plant is unappreciated until, after its death, successive generations have shown the peculiar power of its "blood" to transmit valued characteristics. Messenger is appreciated more by horsemen every year. The peculiar value of the Blue Stem wheat plant, No. 476 of 1892, was not generally known until the several strains of wheat from the various wheat plants had been grown in the field trials for some years, and until the one springing from this plant had outstripped all the others as a valuable variety for practical planting in several States. Peter M. Gideon dug up many thousands of apple seedlings, and yet he is regarded as peculiarly fortunate in securing such a large proportion of valuable apple varieties from his extensive plantations of seedlings.

Luther Burbank, of California, in his work in producing new forms of valuable fruits and flowers, digs up and throws away annually acres of plants in his endeavors to find the one plant in many thousands from which he can produce a new variety with higher economic value or artistic qualities. The Garton Brothers, of England, in producing their new forms of cereal, forage, and root crops, have dealt with very large numbers of individual plants. The breeders of sugar beets analyze annually millions of sugar-beet roots, one firm alone employing 200 people in this work for two months each year, that the "blood" of the comparatively few best mother plants may be incorporated into new strains and varieties.

Cruikshank, the originator of the famous family of Shorthorn cattle known by his name, annually had under his eye very many of the finest Shorthorns of the British Islands, and with wonderful skill brought into his barns those very best animals which would most effectively center the blood of the best meat-producing quality of the whole breed into one herd. His philosophy, his artistic skill, his business ability, his far-seeing patience, and his long life resulted in his forming a subbreed of meaty Shorthorns which has made him famous and has produced great wealth for growers of cattle and users of meat.

Utilizing large numbers of the larger domestic animals, or such plants as forest trees and even some large fruit trees, is often so expensive as to be almost prohibitory. On the other hand, the breeder of wheat, corn, asters, or geraniums can inexpensively use large numbers and make correspondingly rapid progress. The principal part of the work in breeding is in eliminating the many poor ones, and plans for doing this effectively and cheaply without danger of discarding the few desired plants are very necessary. It is but natural that many of these broader laws or principles of business practice in plant breeding are being worked out by persons who are dealing with varieties and breeds with which it is practicable to employ very large numbers. Wheat, in addition to the advantage of using immense numbers at small cost, has many other characteristics valuable to the student of breeding and heredity. The "performance record" of each individual can be measured in a number of its important characteristics—as yield in weight of grain, quality of grain, size of kernels, height of plant, etc.—and these values may be expressed in numbers, so as to be averaged for a series of plants in one year or for a series of years. The seeds from each plant being numerous, a small plot can be planted from each of several mother plants, and by securing their averages of yield, quality of grain, height, etc., the transmitting powers of the respective parents may be easily compared. Field varieties may be developed from each of the several best stocks, and these, at a reasonable expense, may be tested in field trials as to yield and also as to their milling properties. Moreover, the seeds may be preserved for a number of years, so that the original variety may be grown and compared with progeny which has been bred for a series of years. The hoped-for benefits from extensive experiments in plant breeding being so great, it would seem that those interested in plant production and those concerned in the country's welfare would no longer be content until this work is placed on that adequate scientific and financial footing which its requirements and its importance demand.

GENERAL FACTS CONCERNING HEREDITY.

Many important facts concerning heredity and variation in their relation to plant and animal improvement are easily understood. There are innumerable facts and intricate theories regarding the cell and its contents, concerning fecundation, the development of the embryo, the growth of the individual and its life and death, which interest and fascinate the student. These interesting and highly important facts are so numerous that they may entice the would-be improver of plants to continue a student and not a practical producer of values. On the other hand, those who seek for values are too much open to the accusation of not properly reading, and of not recording for others the way nature would have the breeder follow in producing new forms. Both classes of men are needed; also those who broadly combine the scientific and practical.

Some of the important principles and facts to be observed in improving plants may be enumerated as follows:

(1) The individual plant produced from a seed is the important unit in plant breeding. The "bud unit," though of much consequence in case of marked bud variation, is usually of minor importance.

(2) Heredity, centripetal-like, enables us to produce from certain choice plants many descendants which, on the average, quite resemble their parents.

(3) Variation, centrifugal-like, causes the production among the descendants, along with very many average plants, of a few very good individuals and a few very poor ones.

(4) By selecting those best plants which upon trial produce superior progeny, the whole variety may be slightly or considerably improved.

(5) Since the plants of each succeeding generation also vary, by repeatedly choosing the best the variety or race is further improved.

(6) In many cases crossing increases the average vigor of the progeny, but in other cases it decreases the average vigor, size, or other desirable characteristics.

(7) In all cases crossing increases variation, as a rule, both toward better plants and toward poorer ones, thus giving opportunity for selecting from among the best plants individuals which are superior, as progenitors of varieties, to any individuals which could have been secured without crossing.

(8) New varieties can best be founded upon one to a dozen superior selected or cross-bred seedling plants used as parents.

(9) Very large numbers of individuals must be used from which to select or breed in order that mother plants may certainly be discovered from which superior varieties will spring.

(10) In addition to growing large numbers, the breeder of plants should grow all the plants of a given stock under uniform conditions, that they may be accurately compared.

(11) The testing of the finished variety must include adaptability to the soil and climatic conditions, the quality and value of the resulting crop, and the relative cheapness and practicability of its production.

THE USE OF VARIATION ILLUSTRATED.

Variation occurs in each and every characteristic of every class of living organisms. While nearly all of the individuals of a species, variety, strain, breed, or family resemble the average of their class in any chosen characteristic, there are a few which excel, and also a few which are considerably below, the medium in that quality.

This has been illustrated by Quetelet in taking the heights of many men chosen from the same race and reared in the same country. If a thousand men are arranged in a row in order of height, it will be found (1) that the man in the middle represents the average height of all the men; (2) that a line drawn over their heads will deviate from the horizontal but slightly throughout nearly its entire length, falling slightly toward the end where the shorter men stand; (3) that near the upper end the line will rapidly curve upward, and that near the lower end the line will rapidly curve downward. Figure 1 is the graphic expression of these facts. The men range from four feet and a fraction to nearly seven feet in height, the average being about $5\frac{2}{3}$ feet.

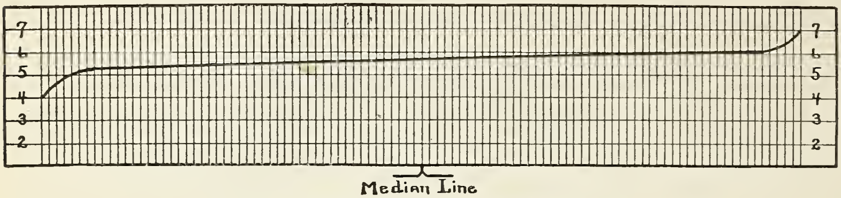

FIG. 1.—Graphic expression of Quetelet's law.

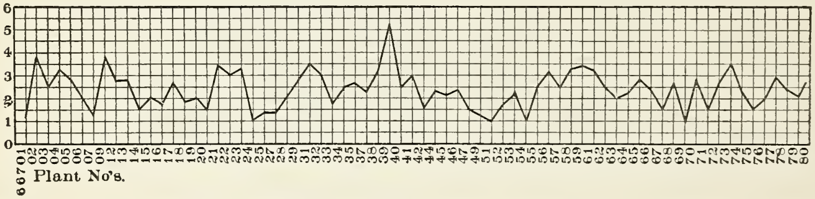

FIG. 2.—Yields, in grams, of 80 Power's Fife wheat plants grown in field-crop nursery, arranged in order as numbered. Each perpendicular line represents an individual plant, and the yield in grams is indicated by the horizontal lines numbered on the left, the length of line below the zigzag line representing the yield.

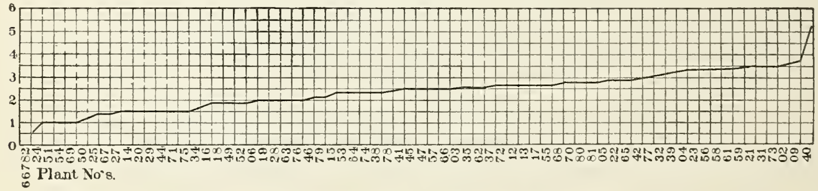

FIG. 3.—Yields, in grams, of 80 Power's Fife plants (the same as shown in fig. 2), arranged in order of yield.

The writer has applied this form of graphic expression to characteristics of wheat and other plants where the measures of qualities may be expressed in numbers, which in turn may be represented by the heights of vertical lines. In figure 2 is shown the yields of 80 individual plants of a new Fife wheat, which had been closely selected to type for some years, as they stood consecutively in a nursery centgener where each plant had 16 square inches of room. The vertical lines to the point where they are intersected by the curve represent the yields in grams, as shown by the figures standing at the left of the horizontal lines, the distances between which represent half a gram.

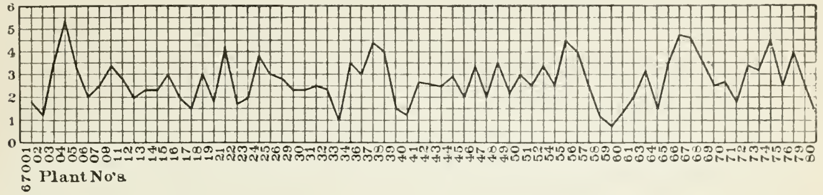

FIG. 4.—Yields, in grams, of 80 plants of Blue Stem wheat, arranged in order as numbered.

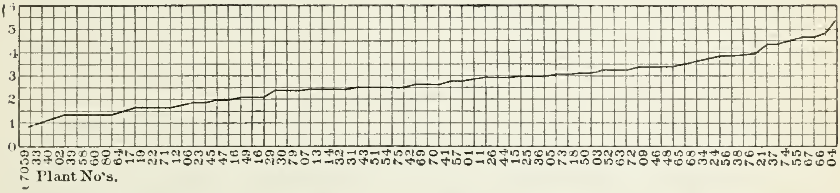

FIG. 5.—Yields, in grams, of 80 Blue Stem wheat plants (the same as shown in fig. 4), arranged in the order of yield.

In figure 3 these plants have been arranged in the order of their yield, displaying the curves. In figures 4 and 5, in like manner, are shown the yields of 80 Blue Stem plants, also long bred to a uniform type. In figures 6 and 7, in like manner, are shown the yields of 86 plants of a recent hybrid between Fife and Blue Stem wheats. It will be observed that there is much greater variation among the plants in the hybrid variety than among the plants of either parent variety. Accidents happen to many wheat plants, even in the carefully arranged

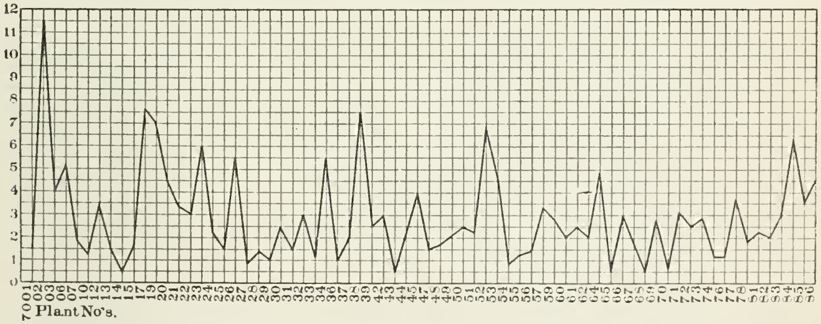

FIG. 6.—Yields, in grams, of 86 Fife-Blue Stem hybrid wheat plants, arranged in order as numbered, much greater variation being shown than in the parent varieties illustrated in figs. 2 and 4.

nursery; there is an abnormally large "infant mortality" and a large number of poorly yielding individuals, as shown in these curves.

This graphic expression is shown in its application to wheat selection in the more formal or theoretical curves in figures 8, 9, 10, and 11, based, only in a general way, on results of experiments in the field-crop nurseries and field-plot tests at the Minnesota experiment station. In figure 8 the solid-line curve cuts the vertical lines so as to represent the individual plant yields of 100 plants of Fife wheat, and the dotted-line curve does the same for 100 Blue Stem plants, arranged from left to right in the order of their yield in grams. The double horizontal line represents the mean between the field yields of these two varieties, as averaged from numerous field trials, and approximately the mean between the average yields of the plants of these two varieties in the field-crop nursery, where each plant has an area of 16 square inches, one plant in a hill, with a 4 by 4-inch space allotted to it. Since two standards of yield are used in these graphic expressions, an explanation is needed. Varieties of wheat yielding 20 to 30 bushels per acre in ordinary field-plot culture were planted also in the field-crop nursery plots, where the individual plants, standing singly in hills 4 by 4 inches apart and cultivated, yielded on an aver-

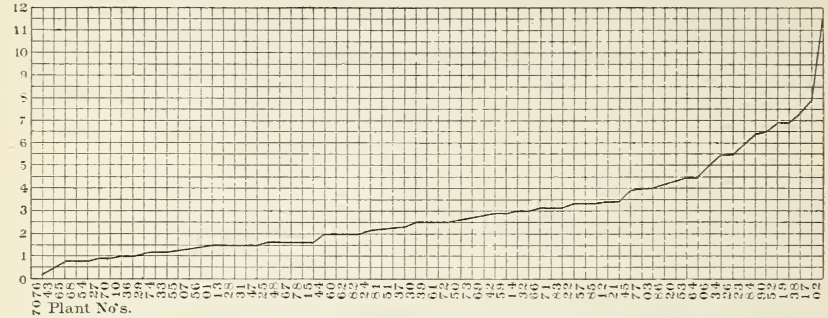

FIG. 7.—Yields, in grams, of 86 hybrid wheat plants (the same as shown in fig. 6), arranged in order of yield.

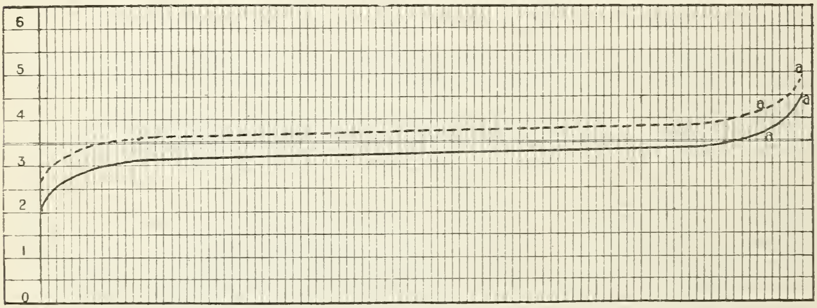

FIG. 8.—Yields, in grams, of 100 Blue Stem and 100 Fife wheat plants compared, the broken line representing the former and the solid line the latter. The mean yield is indicated by the double horizontal line.

age 3 to 4 grams per plant. Calculated in yield per acre, 3 grams per plant make a much greater yield than that of the ordinary field plot. In reading these graphic statements, based on general facts, this difference must be recognized in passing from the yields in grams of the plants in the plant-breeding nursery to the yields in bushels per acre of varieties grown in field plots.

The double horizontal line, at 23 bushels per acre, serves to indicate the standard average yield of the varieties used as a basis from which superior varieties of hard spring wheats rise under the breeding experiments. Since Fife wheat yielded 22 bushels per acre, as averaged for several years in the first field trials, and Blue Stem 24 bushels, the mean is taken as 23 bushels. In improving the yield of either of these wheats those plants are chosen whose vertical-yield lines rank them in the upper curve, as at *o—o*, plants which vary toward a better yield.

In figure 9 is shown, in addition to the Fife and Blue Stem curves of figure 8, a curve marked throughout by *x*, representing a hybrid between the Fife and Blue Stem wheats. This curve has more slant throughout its central straighter portion, and its upward curve goes higher, while the curve at the other end goes lower. This formal diagram has been so made that the center or average line is the same height as the mean between the parents of the hybrid. The mean here has little significance, since we do not expect to form a variety by using all of the hybrid progeny, but by using only the exceptional plants which rise into the upper curve.

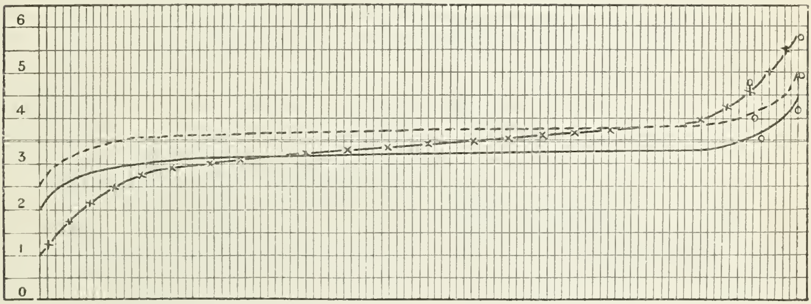

FIG. 9. Yields, in grams, of 100 plants of Fife, Blue Stem, and a hybrid between the two. The yield of the Blue Stem is indicated by the broken line, that of the Fife by the solid line, and that of the hybrid by the line marked —*x*—. The best plants which should be used in further experiments are found near the end of the upper curves at the right and are indicated by *o—o*.

The important features in the hybrid are greater number of individuals from among which superior plants may be selected in the upper curve, and their large yields. These are more promising plants to use as mother plants in seeking varieties with better yields than are any of the plants ranking in the upper curves in the parent varieties. There has been created a power for greater yield. A "reaction" has been produced and the constancy of habit of the Fife and Blue Stem wheats to yield only 22 and 24 bushels, respectively, has been broken. Through the mixture of "blood" the centrifugal force has found a new place to center its efforts against the centripetal or conservative forces of heredity, and we have a few individuals varying in the desired direction of larger yield.

Variations thus newly created in seminally propagated varieties are generally not stable. The force of heredity of the family, race, and species powerfully combat the new characteristics and tend to reduce the new forms to conformity with the old. Most of the plants in the upper curve are very uncertain in their ability to transmit to their progeny their new and superior qualities, and those few which have this quality of strongly transmitting the new valuable qualities are all that have an especial value. Since, as a rule, thousands of their fellows must be eliminated in order to get one good plant, methods must be devised by which this work may be cheaply and effectively done on a large scale. To have many in the upper curve the line must represent very large numbers.

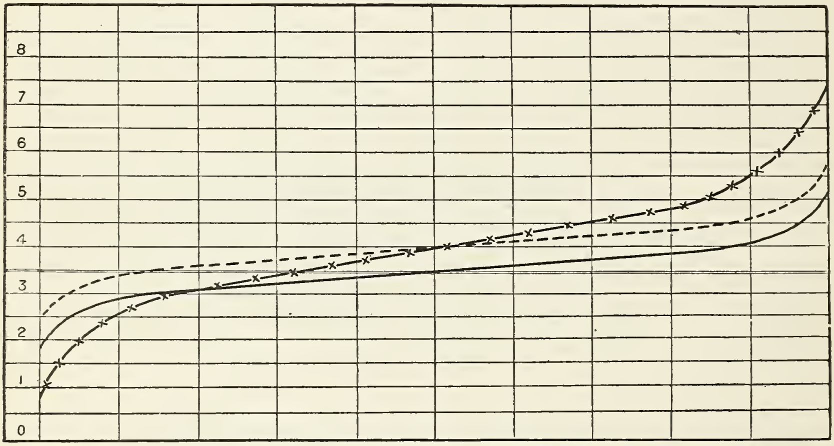

FIG. 10.—Yields of Blue Stem. Fife, and hybrid plants after further selection—all grown from seed from the best plants as, shown in fig. 9 at *o—o*. Yield of Blue Stem is indicated by the broken line, that of Fife by the solid line, and that of the hybrid by the line marked —*x*—. Each of the ten perpendicular lines stands for the average of 100 plants grown in nursery centgener.

The results of a method used for this selection in breeding wheat is shown in figure 10. The 10 plants standing highest in the Fife, Blue Stem, and hybrid curves (Fig. 9, *o—o*), are chosen as 30 mothers of nursery plots of 100 plants each, called, for convenience, centgeners. The average yield per plant in each of the 30 centgeners is a measure of the ability of the respective mother plants to produce progeny which yields heavily. These average measures can in turn be shown graphically, as in figure 10. Here it will be observed that the same general curve prevails; also that some of the progeny of mother plants whose individual yields ranked in the upper curve in figure 9 now falls below the double horizontal line. In other words, some plants which yield well individually produce progeny decidedly low in yielding power, thus illustrating the fact that all but the few in which the new quality persists must be discarded. In trying to raise the yield above the average we must eliminate not only the poor but the average blood, retaining only the blood of the few which have the greatest ability to produce progeny with exceptionally large yield.

But the important result is that some of these new stocks of seeds did give large average plant yields, showing their promise of large yields when grown under field conditions.

Even when those are chosen which yield well in centgeners there is yet need of further elimination by testing them for a number of years in the uniform test field plots. In figure 11 are shown the field yields of the three Fife, three Blue Stem, and the four hybrid stocks which show the highest centgener yields in figure 10. Even here some of those which yielded well in the nursery centgeners yielded less when grown crowded together in the grain field than the varieties used as foundation stocks as shown by their dropping below the standard line. The records of wheat breeding in the Minnesota experiment station show that the yields of new strains and varieties do not necessarily correspond with the yields of their respective mother plants.

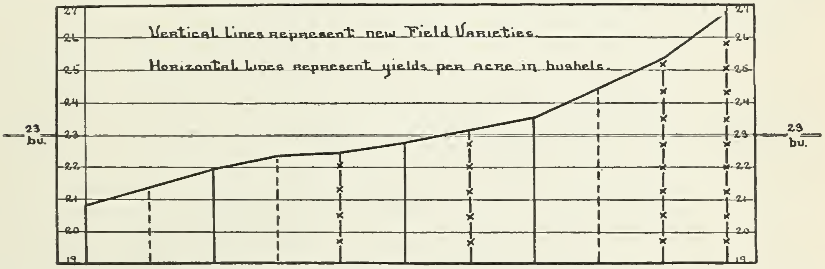

FIG. 11.—Yields, in bushels, of ten new strains of wheat developed in experiments, which have been illustrated in figs. 2–10. The curved line intersects ten vertical lines, representing the yields in averaged field trials of the nursery stocks, which show the highest centgener averages in fig. 10. The three solid vertical lines represent 3 Fife stocks, the three broken lines represent 3 Blue Stem stocks, and the four lines marked with *x* represent 4 hybrid (Blue Stem-Fife) stocks. The line representing the best hybrid strain rises almost to the horizontal line, representing a yield of 27 bushels per acre, while several strains fall considerably below the yields of the parent varieties.

In a general way two facts are illustrated here: (1) That we can improve wheat by selecting the best from our standard wheats; (2) that still more can be accomplished if we create new qualities by hybridizing and then seek from among very many those few plants which will best perpetuate the desired quality.

The real value of variation lies in the ability of the plant to produce plants which individually and in the aggregate yield more and better grain than the average of the same variety. The yield of the mother plant is a very uncertain indication of its use for the mother of a new strain, as is shown in figures 9, 10, and 11, just as Messenger's record as a trotting horse is no index to his great value as the progenitor of the American breed of trotting horses. This fact is shown with force by the history of the progeny of the Jersey bull, Stoke Pogis. He became the progenitor of a great race of heavy butter-producing cows, a purely feminine characteristic, which he could only transmit from his female parents to his female progeny.

RECORDS AND SCORE CARDS.

The careful plant breeder must have systematic methods of testing and recording the qualities of individual plants, so as to secure superior mother plants. Of even greater importance is a system for testing and recording the power of mother plants, i. e., their ability to produce progeny with high average yield, and other desirable characteristics. A good system of records should be adapted to the careful selection of the best introduced varieties; of superior individual plants within the variety; of parents producing superior young; and of resulting strains which, in numerous field trials under the prevailing conditions, prove to be the most profitable to the farmer or other grower and the most useful to the ultimate consumer.

The breeder must have a clear idea of the qualities he wishes to secure. The plant must be studied throughout all its stages of growth, cultivation, and preservation, and new as well as common uses must be understood. The weak as well as the strong points of available parent varieties must be known. Once the ideal is formed, it should be firmly adhered to, only lowered or raised where new knowledge emphatically demands or when previous improvements permit. That the breeder may secure that combination which represents the large general and ultimate value, he must clearly perceive the relative value of the various good characters.

The score card has its dangers, but is, on the whole, a most useful device for keeping records. When applied to perpetuate mere fancy points, as in modern judging of egg and meat-producing breeds of poultry, by applying to them only measures dealing with the qualities of the plumage, wattles, leg scales, and other fancy points, it is worse than useless—an obstacle in the path of progress. Its misuse in animal breeding has usually arisen from the faulty make-up of the score card, especially for those classes of animals produced for their flesh. Some valuable qualities have been given too small a weight in the scale of points, as size in the American trotter, or left out altogether, while other nonessential characteristics have often had entirely too much prominence given them. Not only has the construction of the score card been dangerously at fault, but the breeder or judge using it has often failed from not having a just conception of the relative importance of the several points enumerated in the score card. Records of performance and of qualities which can be tabulated and averaged are of the greatest value in the score card or in pedigree records of plant or animal varieties or breeds. They are measures of breeding power made up of the average records of the individual merit of the progeny.

But these weightier factors must not be too closely adhered to.

General characters or special features often appear and are seen only by general inspection. These living forms are too plastic to be brought entirely under formal yardstick or cast-iron rules or methods of selection. The breeder must adhere to a general, clearly defined plan, but at the same time he must ever be on the alert to take advantage of fortuitous variations, both among his experiment breeding stocks and among the plants grown for general crops.

In the case of such plants as wheat, timothy, clover, and in fact most of the field crops, which in the aggregate represent such a large amount of wealth, the plant is rarely seen as an individual standing out by itself where it can be compared with and chosen from among its fellows. To deal with these crops they should be planted systematically in plots, giving to each plant the same conditions for growth as to each other plant, that all may be compared and the best chosen. Here a scale of points such as is afforded on a score card provides a good scheme for comparing the various characteristics of each plant, and for making a general summarized comparison of all the qualities averaged or grouped together.

Those facts which it may be desirable later on to collect into summarized averages, or to express graphically for comparison, should, where practicable, be recorded in numbers, the unit of which should be kept uniform throughout the series. Thus, in breeding wheat it was found that the grades expressed by the ordinary terms of "No. 1 Hard," "No. 1 Northern," "No. 2 Northern," "No. 3 Northern," and "Rejected," formed a confusing mass of data after a few years, whether collected in connection with the various field tests or with the notes of individual plants in the field-crop breeding nursery. The grades are now recorded in the terms of percentage. After a series of years the grades of the respective mother plants of a given stock can be averaged: also the aggregate grades of the centgener broods of their progeny, thus giving for a series of years the average grades of one stock as compared with other stocks.

PERCENTAGE SCORE CARDS.

By giving a different numerical weight to the several valuable characteristics represented in the score card, those to which the breeder's attention should be mainly directed are set out in bold relief.

In the following score card, used in comparing strains and varieties of wheat in field tests, the attempt was made to place the larger values on those points where lies the greatest source of profit to the grower:

Basis for percentage score card for comparing varieties of wheat (*see fig. 12*).

Yield per acre	45
Grade of grain	20
Rust resistance	10
Quality of gluten	10
Amount of gluten	5
Coefficient of rise of gluten	10
	100

It will be observed that no botanical characteristics nor other distinguishing marks, nor fancy points are given a place. The whole of

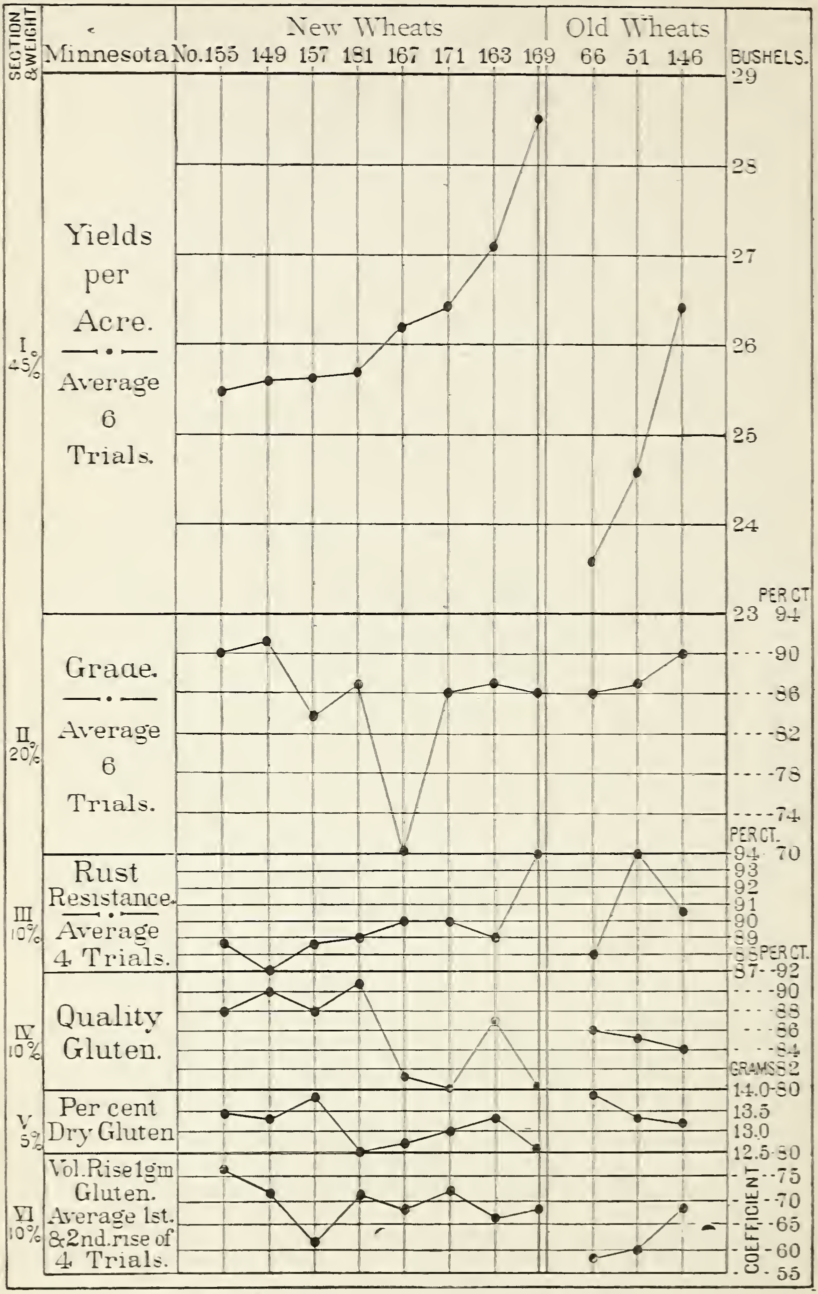

FIG. 12.—Graphic score card comparing wheats.

the 100 points of weight are given to the wealth-producing values. And the important characteristics, at least those to which our farmers at present need to give most attention, are given the largest number of points. The great need is of varieties which will yield heavier crops per acre. With the foundation varieties employed in breeding wheat, quality of the grain is much more easily secured in the middle Northwest than are profitable yields. The product per acre is not half that obtained on the old lands of England, Germany, and France. Therefore, for the present, at least, larger weight should be given in the card to yield than to other qualities.

The factors which should figure in the construction of a score card for any particular line of comparison are usually numerous, much more than is ordinarily appreciated by the framer of score cards for comparing breeding animals. And a percentage score card but crudely expresses the main truths sought.

GRAPHIC SCORE CARDS.

Graphic schemes for displaying important characteristics may sometimes be used to bring before the mind in a compact and simplified form the numerous factors entering into a comparison for the choice of a variety, a strain, or a plant for a particular purpose, or for a combination of uses. This is especially true in the case of choosing two varieties to be mated in the production of new strains or varieties. Here the difficulty is more than doubled, and some scheme is needed which will place the principal elements in juxtaposition where the eye and mind can easily see their relations. Graphic score cards could be made up in many ways and for many purposes. The fact that the size limits the number of points which can be displayed is on the whole an advantage, since the essential characteristics will thus be made to stand out more prominently, there being no room for the unimportant. Whatever form it may take, the scientific study of the score cards and their use in breeding will be found useful and interesting. Such study will aid the animal breeder to have a better conception of an ideal, and a better eye for discerning the specific points and the general value of the animal.

The percentage score card outlined above is reduced to a graphic form in figure 12 by dividing the chart into sections, giving to the respective characteristics spaces proportionate to those listed in the percentage score card. Then in these portions or divisions the several characteristics of all the varieties of wheat compared are graphically displayed. This "graphic" language, if once mastered, conveys the ideas in a much more clear and comprehensive manner than would mere words and figures.

Figure 12 shows graphically several of the leading characteristics of eight newly originated wheats, and, on the right side, three old wheats. Of these latter, Minnesota No. 51, Hayne's Blue Stem, is the parent of the best new wheat shown—Minnesota No. 169; and Minnesota No. 66, Power's Fife, is the parent of Minnesota No. 149.

The horizontal lines represent yields, grades, etc., of the respective varieties, which are given by number or name at the tops of the lines. In each of the six sections there are vertical lines representing units of the various qualities. These run only through the range of figures as given at the right ends of the lines, which include only the variations in yield, in grade, or in other qualities in their respective sections, and not the entire yield, etc.

In section 1, at the right, the yields per acre are expressed in bushels of 60 pounds each, and since the yield is the quality to which the most value is attached, the new and also the old varieties are arranged throughout the chart in the order of their yields.

In section 2 the grades are expressed in percentages, thus making the comparison of yield and grade comparatively easy in the two sections.

In section 3 is given the relative rust resistance of the several varieties, as expressed in percentages of rust showing on leaves and stems during ripening.

In section 4 is given the quality of gluten as determined by an expert in stretching and manipulating the gluten from which the starch had been washed out with cold water. (See Pl. I, fig. 1.)

In section 5 is given the percentage of dry gluten in the flour.

In section 6 is given the quality of the flour as determined by the bakers' sponge test (Pl. I, fig. 2), expressed in the volume of loaf produced by each percentage unit of gluten. This is obtained by dividing the grams of dry gluten in 100 grams of flour into the volume of loaf of dough produced from the hundred grams of flour. These figures represent the averages between the volumes of the first and second rise of each kind of flour.

This chart is an aid in the selection of those varieties between which hybrids are to be made. The new wheat known as Minnesota No. 169 stands out prominently as the best wheat, and as one of the parents to use for crossing to produce further desirable variations which may serve as foundations of new strains or varieties. Minnesota No. 163 is the next best yielder, has grain of good grade, is fair in rust resistance (a point in which No. 169 is very strong), is good in quality of gluten, very good in the amount of gluten, fair in amount of loaf a given amount of gluten will make, and should serve well to cross with the large-yielding No. 169.

Minnesota No. 171 would also be a promising wheat for hybridizing with No. 169. No. 167, on the other hand, while nearly as large a yielder as No. 171, is deficient in grade of grain and in the quality of its gluten. Minnesota No. 149, though not so large in yield as some others, grades high on the market, has a relatively large amount of gluten of very superior quality, and would rival No. 163 to hybridize with No. 169.

METHODS OF PLANT BREEDING.

RELATION OF PLANT INTRODUCTION TO PLANT BREEDING.

In addition to the limited number of native plants suitable to special cultivation in each locality, every country finds it advantageous to introduce plants from other countries, and to transfer plants

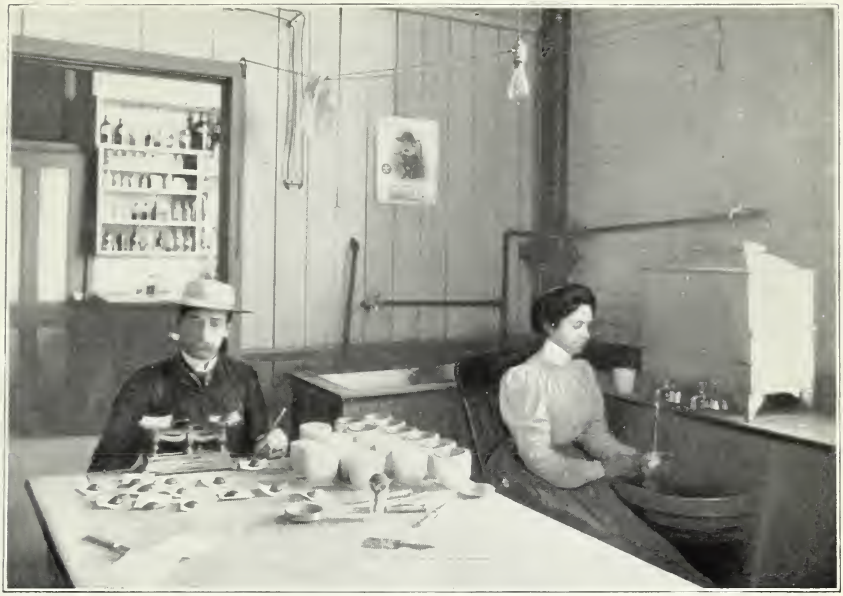

FIG. 1.—TESTING THE GLUTEN OF NEW WHEATS AS TO ITS AMOUNT AND STRENGTH.

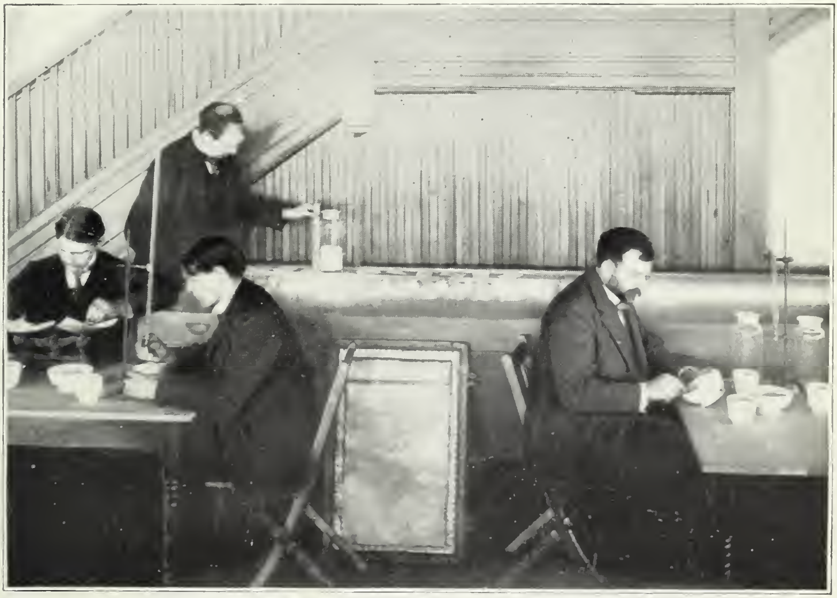

FIG. 2.—MAKING THE BAKERS' SPONGE TEST OF NEW VARIETIES OF WHEAT.

from one district or neighborhood to another. The number of foreign plants which the Department of Agriculture is introducing into the United States through its trained agents is very surprising to one not acquainted with the facts, and there is a constant transference of varieties within the country to localities new to them. These agents, by becoming acquainted with the various local conditions of our own country, and then seeking plants in foreign countries having similar climate and soil, are able to understand the needs of each locality and to introduce plants which will thrive and become useful. As illustrating the extent of the work in this line which it is practicable to do, it may be mentioned that in Minnesota several hundred kinds of wheat have been introduced, mainly by the experiment station, and somewhat lesser numbers of several other cereals; also numerous species and varieties of forage and root crops, besides hundreds of varieties of apples and other trees, small fruits, and flowers. From the station the most promising varieties are transferred to the substations, to a dozen trial stations distributed throughout the State, and to many farms from which reports are required. And when it is observed that a somewhat similar work is maintained in each of the States and Territories of the United States, it may be seen that plant introduction is a prominent feature. With the national Department of Agriculture encouraging, leading, and directing the main features of this work, the whole is held together in a helpful way, and good results are being realized. Seed and nursery firms, private individuals, and agricultural and horticultural societies are also doing much to assist in adapting varieties to special conditions.

That this line of helpful work is not overdone is shown by some of the recent beneficial results. *Bromus inermis*, an important forage grass for the drier areas of the Northwest, and Dwarf Essex rape, a forage plant suited to providing succulent forage in early and late autumn, are examples of new crops of very great value in the Northwest. The tea and the many new plants from the Mediterranean regions which are being introduced into the South and Southwest by the Department of Agriculture illustrate the fact that there are regions elsewhere from which only part of the plants have been heretofore brought to this country for thorough and fair trial. Each of the varieties now existing in each locality in other countries and those being bred for special conditions by our foreign friends may fit into some locality, broad or limited in area as the case may be, in our own country. And, likewise, plants which are so changed as to suit special environments in our country may find their special niches in one or more foreign countries. We have a case in point in Indian corn. In America this crop has been bred for numerous conditions. Early, large-yielding dent varieties have finally been bred for southern Minnesota and other Northern States. In Europe only those large-yielding varieties of corn from the South have been tried, and they have been pronounced a failure. These cold-region varieties have not been tried, but would probably succeed well for growing fodder and silage; but of even greater importance is the fact that these varieties would be the best foundation stocks to utilize in breeding kinds of corn suited to growing the grain as well as the fodder in many European localities.

Liberality of plan in introducing and testing new plants is the part of wisdom. In not a few instances plants have not at once fitted into their proper niche, and some useful kinds have been wrongfully discarded. For example, *Bromus inermis*, mentioned above, was tried by several experiment stations and by numerous farmers throughout the middle West for a number of years, and no one saw in it anything of especial promise. Attention was brought to it by the Canadian experiment stations at Brandon, Manitoba, and at Indian Head, Assiniboia, and, upon further and more extensive trial, it soon became popular in the Dakotas and adjacent States. Its recent wide distribution by the national Department of Agriculture, aided by experiment stations of the interested States, is proving to be of great value.

Some introduced varieties and species which seem, as compared with the better standard sorts in any district, to be of too little value to be useful, may be so changed as to fit their new conditions, or they may have special uses not commonly regarded. Thus, some of the hardy Russian apples introduced throughout the middle Northwest by Prof. J. L. Budd and others may prove useful only as a source of hardy apple "blood" in the formation of hybrid races which will endure the severe winters of this northern climate. Mr. Luther Burbank, of California, has introduced into his plum-breeding nursery many types of plums, which he crosses or permits to cross in all conceivable combinations, that he may secure seedlings of types almost innumerable, from which he may select the few which are really valuable. Some forms of Speltz wheat have not proven to be a profitable crop in Minnesota, yet a small infusion of their blood into the so-called Blue Stem variety may be of value. The Blue Stem shells out badly as soon as ripe, while the Speltz has chaff which remains firmly attached to the kernel, and a little of the Speltz blood might be used to correct the greatest weakness of the otherwise very good Blue Stem variety.

CHOICE OF FOUNDATION STOCKS.

The plant breeder wins half of the battle when he secures suitable foundation stocks. To do this often requires the extensive testing of introduced and standard varieties in the locality and under the conditions for which the effort is to be made to breed improved varieties. But as a rule there are standard varieties commonly and successfully grown in the vicinity which will serve until, by further variety testing, better stocks are secured. The earliest efforts at breeding any species are often experimental as to the methods to follow, and a mediocre foundation stock will serve at least to practice upon, so that when the better varieties have been found the work may be undertaken in a thorough-going manner. There are many matters of detail to learn, and the most practical way to master these details is to begin the actual work at first on a more modest scale than is advised for the general work later on. As the work progresses the testing of introduced and standard varieties and the results obtained from new kinds—if full records are kept throughout—will show from which foundation stocks it is the best to try to make new strains or varieties. It occasionally happens in the experience of the observing breeder that some chance form will be found which is so much nearer the ideal for which he has been systematically seeking that he should use it for his foundation stock, discarding all or most of the products of his former labors. It often pays to seek long and far for these unusual forms and individuals among the plants of a wild or native species that the best available foundation stock may be secured.

NAMES AND NUMBERING OF VARIETIES.

The nomenclature of varieties of cultivated plants presents many vexing problems. Seedsmen are prone to multiply names by creating synonyms for new or even old standard sorts, that they may have what at least appear to be new varieties for their customers. On the other hand, the class name too often adheres to the selected stocks in cases where improvement in yield or other quality has been produced, but no visible botanical change has been made; and the new strain, having no special distinguishing mark, is classed with, and probably wrongly condemned with, the parent variety. And in many cases in wind-pollenized species, such as corn, a once distinct variety is changed by admixture with other varieties, and what is known by a certain variety name in one locality is soon quite different in value or in appearance from what is known in another locality by the same name and which had, in part, the same origin.

Variety testing, an essential part of the experiment station work, is an invaluable adjunct to the seed and nursery business, and is advantageous on the farm and in the orchard and garden. It is necessary to test varieties that we may know which produce best, and also that we may be able wisely to select foundation stocks for the work of making better varieties by breeding. Unless the figures or general statement of results regarding the test applies to a definite variety or stock of seeds it is valueless, or even may be misleading and harmful. The principle of cooperative testing of varieties by experiment stations is properly growing with rapidity, since experiment stations which are equipped for this work can not only do much of it better than growers, but they can greatly save in the aggregate expense. There is a part of this work, however, which must be done by the grower, since all his conditions can not be duplicated on the experiment farms.

The Minnesota experiment station has adopted a system of numbers for varieties, using variety names more as class names. This plan grew out of necessity. Several superior strains or subvarieties of Blue Stem wheat and Fife wheat, for example, had sprung up among the farmers and at the experiment station. These could not be clearly identified by any botanical characteristic, but some of them were superior in their yield.

The following general plan has been in operation for several years and has given excellent satisfaction:

(1) Whenever a sample of seed is received from any source it is given a number with the words "Minnesota No." prefixed, written thus: "Minnesota No. 169 Wheat;" "Minn. No. 13 Corn," etc.

(2) In a book called the "Minnesota number book" each variety is entered separately, and its subvarieties are numbered consecutively as they are received by the station and its substations.

(3) Whenever a new subvariety is taken from the field-crop nursery to the uniform-test field plots, it also is given a number, taking the next number to the one last entered.

(4) In the Minnesota number book are entered in appropriate blank forms all facts obtainable regarding the name, source, and origin of each particular sample of seed which may form the basis of a new variety.

(5) A small number of the plants of a newly introduced strain or variety are grown, and full descriptive botanical notes are recorded under each, that its identity may not be lost.

(6) For our purposes the number, with the words "Minnesota No." prefixed, thus becomes the name of the strain or variety, and in case it is of our own breeding there is no other name given, and the experiment station desires that no one else give it another name.[1]

(7) By keeping this number and the identical stock of each seed together inviolate we can attach to it a performance record. And the association of the name, the record for large yield, and the identical stock or variety which made the record, is what gives peculiar pedigree value to the seeds.

(8) This plan of numbering, or naming with numbers, is useful in cases where a variety is improved from year to year, since when the old no longer represents the improved variety it can be given a new number. Thus, Minnesota No. 13 corn has been sold to the farmers for several years. During each year a field of stock seed has been grown, called our "seed-corn patch," in which this corn has been rigidly selected for better yield, but not to change the appearance. The seedsmen and many farmers are now annually selling large quantities of Minnesota No. 13 seed corn, some of which is from seed sold by the experiment station in the years when the improvement of this corn had been only begun. We shall now give our improved stock of this variety a new number (Minnesota No. 172), and advertise it as an improved progeny of Minnesota No. 13. Names being easier to remember

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[1] Seedsmen should not give a name of their own choice to a variety with such a record of performance, and thus lose the connection between the name, the performance record, and the seed, or doubly violate good ethics by appropriating to themselves both the name and the experimental record, for which only the experiment station which tested it can stand responsible.

than numbers, they are better in such cases, as fruits or potatoes which are reproduced by cuttings or grafts, where the variety can be definitely described botanically. It is expected that occasionally, when a newly originated variety of field crop especially distinguishes itself for peculiar value, it may be given an additional name as an especial distinction of merit.

(9) Since many very valuable new varieties never gain commercial recognition, and their originators secure neither credit nor profit, the need of adequate business methods in installing among growers each valuable new variety is of great importance. Experiment stations and the General Government need plans adapted to each new class of varieties originated, as do also seed firms and amateur breeders. Gift packages accomplish this in some cases. In others useful new varieties are thus discredited and wholly or partially lost. Strong seed merchandising firms and large numbers of experienced seed growers are most important agencies. The Minnesota experiment station has had most encouraging success with its plan of distributing no gift packages, but selling under pedigreed certificates to picked growers of seeds, each of whom becomes a propagator for profit. The station thus fosters the business interests of its many cooperators. Their desire to retain the opportunity to cooperate in introducing successive new varieties stimulates these cooperators to employ good methods and fair dealing.

BREEDING BY SELECTION.

The general plan to pursue in breeding plants is here divided into two sections, in order that selection may be dealt with before taking up the more complex question of combined hybridizing and selecting. Selection is of two kinds: (1) Selection of seedling plants, and (2) bud selection.

SELECTION OF SEEDLING PLANTS.

Most of the variation in plants has its origin in reproduction from seed, the variation being, as a rule, the greater the more distant the relationship between the two parents. This variation shows strongest among the seedling plants, and to a much smaller extent among the plants produced from the buds or cuttings taken from the seedling plant.

While half the battle is won by choosing the variety to serve as a foundation stock, more than half of the remainder is often won by the first one or two years' work in selecting mother plants within the chosen variety. For example, the writer, in starting to breed from several varieties of flax, used 100 seeds from the bulk grain of each of seven varieties. The plants were grown singly in hills a foot apart each way. It was desired to choose from among the plants of each variety one plant for a mother of a stock to be developed into a strain or variety yielding a large amount of seed per acre, and a second plant to serve as the mother of a tall-growing strain or variety for fiber. Upon inspecting the several plots the range of choice among the individual plants was not nearly so great as had been anticipated. There were no good types of heavy-yielding plants, and few, or none, remarkable for their height.

In the same field with the crop nursery the seven varieties of flax were growing in large field plots. There was occasionally a very tall plant, and by diligent search plants were found which had a very much branched top, and were apparently heavy seed bearers. A tall plant and a heavy seed-bearing plant were chosen from each variety. The next year 100 seeds were planted from each of these 14 mother plants. The plants from the tall mothers averaged several inches taller than those from the heavy seed-bearing mothers, though the latter had not been chosen for low stature, and the supposition is that they were of average stature among the plants of the respective varieties from which they were selected. Thus, the first year the selections were made among very large numbers, and the second year the mother plants were tested by comparing a large brood of the progeny of each.

In the accompanying illustration (Pl. II, fig. 1) are shown the results of the experiments in the improvement of flax by selection:

The bundles at the right in the lower row are several samples of flax bred for branching tops with many seed bolls, no effort having been made to change the height by selection.

The six bundles at the left have the same parentage as the seven in the same row, but were bred by selection for greater length of straw. All the bundles of this row are from plots planted at the rate of over 2 bushels of seed per acre, as in growing crops of fine fiber.

Seeds from the same stocks were planted thinly, less than 3 pecks of seed per acre, as for growing crops of flaxseed, and bundles of the resulting plants are shown in the upper row.

Whether grown thickly or thinly, the newly bred qualities of tall growth and fine stems showed in the plants grown for fiber, which stood several inches taller than those grown for seed, which remained the same height as the plants of the original parent varieties. The proof is very strong that long, fine fiber can be grown in the dry climate of the Northwest. Flax bred to grow tall will make fiber in Minnesota closely approaching in length, fineness, and strength that grown in western Europe under moister conditions.

The most important feature of this experiment to Minnesota is the yield of the flax bred to grow seed. The tests of yield for seed have not yet been completed, but since such a profound change has been made in the height of those grown for fiber it would be very strange did not some of the strains shown on the right prove very heavy yielders of seed.

From some of the best of these mother plants the experiment station now has seed, as yet only in sufficient quantity for field tests, of seven strains of tall-growing kinds of flax, and seven others which are apparently superior in their yield of seed. If the stocks first planted in the field-crop nursery (among which relatively little variation was found because of the small number) had not been discarded and had the mother plants been chosen from among them instead of from the fields, where there was a large number to choose from, it is probable

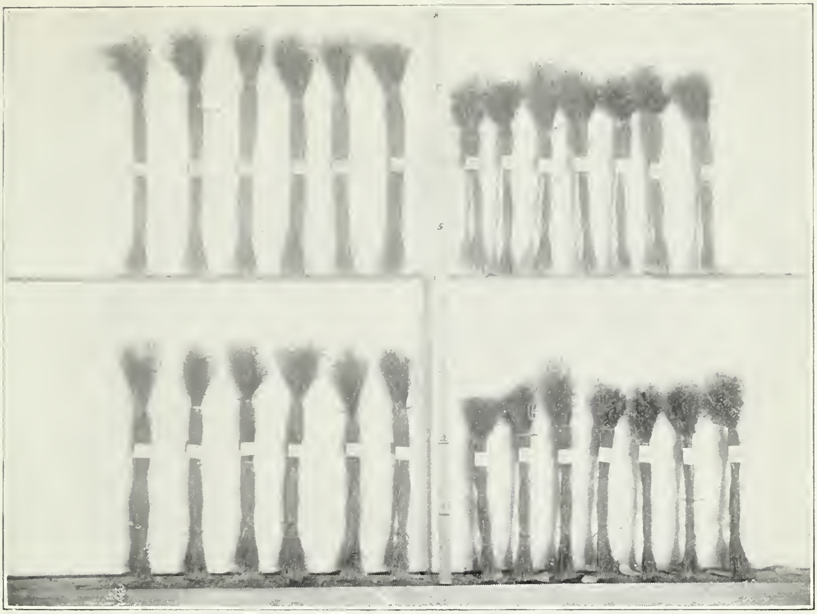

Fig. 1.—Improvement of Flax by Selection.

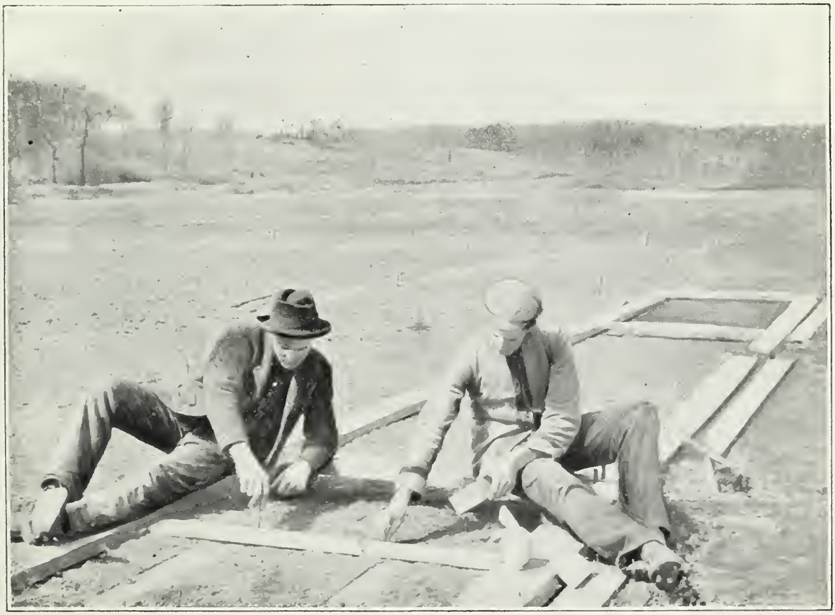

Fig. 2.—Planting Seeds in the Crop Nursery.

that progress in making useful new varieties would have been very much slower. It was practicable to select choice plants from the field of flax, because each seedling plant stands out distinct on its single main root, while it is not practical to thus select in case of wheat, which sends up numerous culms from each seed, the culms from two or more seeds often being interwoven.

While the general principles of breeding are the same throughout, their application must vary greatly, according to the habit of the species dealt with. One plan is best with open-fertilized species, another with close-fertilized species. Species freely cross-pollinated by the wind may require different treatment from those occasionally crossed by insects. Varieties propagated mainly or wholly by cuttings require different plans from varieties propagated by seeds. Annuals often require a different method of selection from that used with perennials. In case of varieties used in one locality which are produced from seeds or bulbs grown in another place, the breeding requirements differ from those where the seeds are bred in the same environment under which the crops are to be grown. The whole range of special means and requirements for breeding the thousands of varieties for many localities having different conditions can hardly be more than touched upon. Further on a somewhat detailed plan for breeding several crops will be given as examples, showing how the systematic improvement of a plant may be worked out.

BUD SELECTION.

While efforts should be mainly directed to a choice among seedling individuals, yet the variation among the buds, branches, spikes, or heads of the plants is sufficient to warrant general and in some cases special attention. While we are warranted in planting the seeds of wheat singly in the hill, that we may judge or test the weight and quality of the crop of seed from each individual plant so as to secure the best plant, we should also secure the seeds from the best spikes. And in case of many flowers multiplied by cuttings, where bud variation is sometimes considerable, marked improvements may be made by bud selection. Each branch, leaf, and flower springs from a single bud, and, though bud variations do not generally breed true to type, they so often do that the selection of marked bud variations is well worth attention. Sometimes a limb, a flower, or other new bud feature does not breed true at once when reproduced. By growing many plants from the peculiar branch the same bud variation may appear on one or more plants, and upon following up nature's hint workable ore may be discovered deep down in the mine. Sometimes we find seminal variations, and more frequently bud variations, which breed true, but as a rule we secure them wavering, as if staggering under a load of inherited tendencies which are trying to reduce them to the level of their species, variety, or family. As the special school takes the youth from among the steady-going things of the country or village home, develops his latent faculties in some line of art or science for which he has shown a bent, and fixes the habits and ambitions of his life on some specialty, so we must discern new powers in plant and animal life, and by means of environment (or by cross-breeding or hybridizing) give it development, and by extensive and intensive selection fix it as a type. And we can not stop with having built up new types. We must not even be content with letting them stand still. The saying that "man can not stand still—he must progress or he will go backward," is as true of improved varieties of plants as of men. Give the Indian boy an education, even educate him as a specialist, and place him back among his own uncivilized people, and he will generally return to nearly their standard of living. The higher a variety is specialized under the art of the breeder and under the nurture of improved conditions, the more difficult it is to keep up its high qualities. Not only must the high nurture be kept up, but the selection also must be continued, or retrogression toward the old primitive type may be expected. Breeding upward specializes a variety of plants or animals for definite conditions, and to secure the full value of the improved blood of a plant or animal it must continue to be kept under those good conditions.

From formal experimentation we may not produce the greatest wonders. These may arise as accidental variations in the course of common plant production. In fact, most of the varieties we now have were originated by picking up these odd forms, and from a small beginning, persistently followed up, greater variation was produced and then fixed to uniform types. The numbers of plants and animals bred under the varying conditions of common production are so vastly greater than the number which the breeders of plants and animals can deal with that it is not strange that a larger number of useful variations arise there than in the small fields and farms of the professional breeders.

As knowledge among men accumulates from generation to generation, there is more impulse for still greater development of thought. The thought of one decade is not only a basis for better thought in the next generation, but it is an exciting cause of new and more complex thought. The throwing together of new thoughts somewhat related, yet distinct, excites the creation of more thoughts. So, while improved varieties are a higher basis upon which to build other new varieties, each pair of varieties which are specialized so as to be very different in character, though related, have within them when crossed the inciting causes, the power of creating entirely new variations. The principles and physical relations or changes of the brain cells involved in the physiological phenomena mentioned are the subject of research as well as the principles and the physical changes of the generative cells in the generative phenomena. The obscurity, if not other features, common to the phenomena of mind and of heredity have led some plant breeders to believe that the mind of man has a direct relation to and influence over his work as a plant breeder, and that some men have a greater power in changing plants than others. When due credit is given to the great care, to the use of immense numbers, to the acute observation in detecting new things, and to the system used in developing, testing, and comparing many new types by those who are most successful in producing wonderful and useful forms, there is so little room for the special direct influence of the mind of the plant breeder that it needs little consideration.

BREEDING BY HYBRIDIZATION AND SELECTION.

In breeding by selection alone the variations occurring naturally or accidentally within the variety are depended upon. Man simply selects the choicest. These are usually placed under such environment as will cause desired characteristics to develop best and to stand out. In breed or variety formation through the agency of hybridization, followed by selection, man plays almost a creative part. Where there is no variation of such nature as desired, it is created by bringing together two of the many forms which have varied from some ancestral forms, yet not so far but that they will cross-fecundate. The further they have departed from ancestral characteristics and formed diverse qualities, the more likely will their progeny exhibit new characteristics made up by combining those which have become so radically different in the two parents. In a group of men conversing about a subject concerning which they have all practically the same knowledge few new ideas are given to each mind in the group, and few new thoughts are created through suggestion to each mind. They separate each with the same knowledge and beliefs as before. But if these men begin conversation about a subject concerning which they have different ideas and beliefs, each mind not only receives new ideas, but the creative power of the mind develops new thoughts, theories, or interrogatory notions, which may or may not be rational. So, when two nearly related plants or animals are crossed, variation is not so much excited, and the progeny are very similar to the parents. But when two plants widely different are hybridized, the natural tendency to vary develops new combinations or apparently creates characteristics, new in kind and degree, which hardly seem to be the combined results of any two characteristics in the parents. Since this comparison seems so useful in carrying to the mind a conception of the nature of heredity and variation, it may properly be carried a step further. The human mind has been built up step by step from the minds of semicivilized races of the past by the association of ideas, resulting in the creation of the more complex knowledge of the present. So the varieties of plants and animals are being built up by the creative power of natural variation. And, as printed pages, the school, the modern railway and steamship, and electrical agencies are furnishing an environment in which the mind develops and new ideas are created more rapidly than ever, so the plowed field, the fertilized soil, the isolated position of the cultivated plant, giving it more nourishment, and especially the bringing together and crossing and hybridizing of various forms of plant life, by accident and by the intentional effort of man, furnish conditions under which varieties are improved and new characteristics are created.

While the American genius for inventing machinery was being developed, indian corn and the American trotting horse were being most wonderfully evolved into higher types. While the Japanese mind has been rising out of the lethargy of ages and becoming a valuable factor in civilization, the sugar-beet plant has been changed from a species which had held its characteristics through an epoch of history to a type profoundly different and of enormous value. As the thought of modern Europe has been centered in America through the migration thither of many of her most progressive people, so Burbank in his garden, and in a broader way all of our farmers and experimenters, are centering the blood of all the valuable plants of the world into varieties which shall improve plant life in our country. When we view the development of the mind of the human race from its original state to its present achievement we can not predict a limit to its expansion in the future. Nor when the development of useful plant and animal forms, through their changes from a simple beginning to their present complexity, is observed, can we assume that there is any practical limit to the betterment of our plant varieties. So far as the present generation is concerned, there is ample room for useful improvements in all classes of economic plants and animals. Since by breeding the value of some plants, as sugar beets, has been enormously enhanced, it does not seem too much to hope that most of our economic plants can be made 25 per cent more valuable than now.

DEGREE OF RELATIONSHIP IN CROSSES.

"In-and-in breeding," "outbreeding," and other expressions relating to the close or distant relationship of parents have been prominent subjects among animal breeders. Charles Darwin's dictum that nature causes benefits to arise from crossing and abhors self-fertilization has been a foundation stone for the theories of writers and teachers upon animal breeding, though many men are skeptical about the application of this statement to some of the many conditions in animal breeding. Plant breeders have even a greater range of conditions as to the degree of relationship between parents, because they deal with the self-fertilized and partially self-fertilized species, as well as with those requiring or allowing of the union of the germs of two parent plants. Possibly Darwin's law would more broadly cover the truth if expressed thus: Nature abhors a radical change which would require species to cross in much closer or in much more radical relationship than is their long-established habit.

It is known that very close breeding among poultry, swine, human beings, and in corn is harmful. On the other hand, wheat and other self-fertilized species, though bred up to a high standard of specialization, as in the production of a large proportion of seeds as compared with the remainder of the plant, do not seriously, if at all, retrograde under self-fertilization, the most incestuous kind of inbreeding, carried on for many generations. And the evidence is most conclusive that some of these close-fertilized species may be materially improved by a system of selecting the self-fertilized plants. The best newly originated variety of wheat at the Minnesota experiment station came from a single mother plant (or may we call it mother-father plant?) chosen in 1892. There is some good evidence also that close breeding in some classes of animals is not injurious, and in many families and herds of animals close breeding, or in-and-in breeding, has been very useful in fixing valuable new types.

The general statement that cross breeding gives increased vigor, size, and value is also too sweeping, and the limitations of the good effects should be better understood. Crossing does often increase vigor, size, and other good qualities, and it often decreases these qualities, and sometimes in radical crosses the average progeny is exceedingly weak, even being so weak in fecundity as to be sterile. This fact was observed in certain wheat hybrids at the Minnesota experiment station, where in a few generations the hybrid stocks became very weak and finally ceased to produce seeds, while other stocks from the same two individual parent plants were very strong and were the progenitors of some of our most promising new wheats. But, so far as the writer has observed, hybridizing increases variation in the first few generations. Swingle and Webber[1] show that many radical hybrids vary but little the first generation, but that all hybrids vary within a few generations. Usually this variation is both upward and downward, though in some cases of radical crosses none of the progeny are equal to either of the parents, and in other cases nearly all are better. As to whether the average progeny of the cross is stronger or weaker than the mean between the parents—"mid-parent," as Galton expresses it—depends in part on whether the parents are properly related, or whether the cross is too radical or too close to suit the habits of the parents. Determining what degree of relationship is best in the mating of plants is, indeed, an interesting subject for scientific inquiry.

In hybridizing plants to form new varieties, large numbers can usually be employed, and the average qualities of the progeny is a matter of no particular consequence. The important feature is that the hybrid stocks vary greatly in the desired direction, giving a few plants which, when multiplied into varieties, will average better than the parent varieties. No matter should all but one in a thousand be discarded, if that one will produce a race of progeny with the improved qualities. With this theory of hybridizing and the practice of making a very large number of crosses, giving each a few years or generations in which to show the tendencies of its progeny when grown in large numbers, and with a systematic plan of eliminating, the use of hybridizing in variety formation becomes a practical and very powerful agency in plant improvement.

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[1] Yearbook, U. S. Dept. Agr., 1897, p. 407.

HYBRIDS AND CROSSES DEFINED.

Very much has been written concerning hybrids, and this literature contains the results of many experiments. Swingle and Webber have summarized the facts well.[1] They use the word "hybrid" to mean a plant resulting from cross fertilizing plants differing in their relationships, whether that difference is great, as in species or even in genera, or comparatively slight, as in distinct varieties. Cross-bred plants are those which have resulted from the cross fertilization of plants within the variety but separated in descent by at least some generations of seed production. Self-fertilized plants, on the other hand, are those which have resulted from the pollen of the same plant impregnating the flower, including those plants which have arisen from buds and cuttings from the same seminally produced plant.

IMPORTANCE AND METHODS OF HYBRIDIZING.

The operation of cross pollinating in hybridizing is easy in the case of most useful plants. This work forms but a small part of the work of variety formation, most of the labor and expense being connected with collecting and testing to find superior foundation stocks, with the growing and selecting of large numbers of hybrid plants and with testing the resulting varieties that only the best may be propagated and disseminated. The methods of hybridizing wheat, corn, and apples, and a few other plants will be given briefly on future pages, as illustrative of the work with some classes of plants. It is necessary fully to understand the structure and habits of the flowers of the plant to be dealt with, but no great skill or profound knowledge need be attained, and the necessary appliances are few and simple. In case of crosses between nearly related plants there is often little more variation than among self-fertilized plants. Where varieties not too distant in relationship are hybridized the variation, according to Swingle and Webber, usually shows in the first as well as in the succeeding generations, but where the relationship of the parents is very wide, as between species or genera, the hybrids are more likely to be intermediate in appearance between the two types for the first generation. By self-fertilizing or crossing the flowers on these plants of the first generation greater variation is produced, and, for a few generations, continued new forms may be expected to result from the variation inaugurated by the hybridizing of the two species or genera. Variation can often be profitably increased by crossing the hybrid back on one of the parent species or by crossing two hybrids of different or partially different parentage. In some cases hybrids persist in remaining intermediate between the two parental forms or in taking and retaining the characteristics of one or the other of the parents. In this case the only utility of the hybrid may be to serve as one parent to use in making still another hybrid; or it may be wise at once to discard it, that more attention may be given to hybrids which show variation. Garton Brothers, of England, who have done most commendable work in producing hybrids among field crops, say that "the effort should be to secure a reaction," meaning that those crosses are most desirable which cause excessive variation or a multiplicity of types, some of which will probably be found useful new forms from which superior varieties may be developed. Where the relationship is very distant the hybrids are likely to be weak in fecundity or in some other vital characteristic, though progeny of great value sometimes occurs.

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[1] Hybrids and their Utilization in Plant Breeding. Yearbook, U. S. Dept. Agr., 1897, pp. 383–420.

BREEDING FOR SPECIAL AND NEW USES.

While our best efforts should be directed toward better fitting our staple crops and our commonly used plants for their accustomed fields of usefulness, there are special and new uses for plants which should receive attention at the hands of plant breeders and plant introducers. This work, which was emphasized in previous paragraphs, can be accomplished in part by selection, but even more thoroughly in most cases by hybridization, followed by selection. To extend the growth of some species to regions in which they do not now succeed, varieties are needed which will endure more cold, or more heat, or more drought, or more wind, or more alkali, or be adapted to other features of new surroundings. Many of the changes needed for these purposes could not be bred into the varieties, especially in case of close-fertilized species, by selection alone. New varieties must be created by hybridizing. The work is sometimes quickly accomplished, and sometimes results come very slowly or not at all. Resistance to disease is a quality of superlative importance in many instances. Sugar beets have been enriched in their percentage of sugar content, and made more valuable by lessening the amount of solids other than sugar which are expensive to remove in the manufacture of pure sugar. Since sugar beets are an open-fertilized species, the natural crossing of the plants has doubtless been a powerful agent in creating this new value in the roots. Corn is being made a better food by increasing its content of nitrogen compounds, collectively called protein.

BREEDING NITROGEN INTO FIELD CROPS.

There are few general considerations in the breeding of plants and animals which are more important than that of breeding a stronger tendency toward the production of nitrogen compounds. Protein is worth, on the average, about 4 cents per pound in those substances used for food for animals and man, while carbohydrates and fats, excepting in special forms, as in highly flavored butter, are worth much less. The farmer can produce starch, cellulose, and sugar in his staple field crops for a small fraction of 1 cent per pound, often a very small fraction. The carbonaceous substances contain neither nitrogen nor mineral fertilizing substances, and their use as plant food is limited to improving the water-holding power of the soil, and, upon decaying, furnishing active compounds which help to elaborate plant food from the insoluble mineral and nitrogen compounds in the soil.

On the other hand, the protein of our food plants, in addition to being very valuable as a food, is a most important fertilizer. In addition to its value of about 4 cents per pound as a food stuff, protein compounds are worth, at the commercial rate of nitrogen, about 2 cents per pound as fertilizers. Assuming that half of the nitrogen can be retained for fertilizer on the farm upon which the crops of grain and forage are grown and fed to animals, we have 1 cent per pound valuation of the protein in the foods we raise for our animals as a manure to add to its value of 4 cents per pound as a food for live stock. These values can not all be secured and realized by the farmer, because he sells some of his crops in the cities. We should seek to increase the yield of nitrogen per acre, as well as the total yield of crop, just as the breeders of sugar beets must increase the yield of beet sugar per acre rather than the tonnage of the roots, and the breeders of dairy cows increase the yield of butter rather than the yield of milk. Thus we should add to the protein content of our cereal and forage crops. In case of corn fodder there is a special reason for increasing the content of protein. The varieties of corn used for dry fodder or for silage already yield so well that a superabundance of roughage can easily be produced. But to make it valuable as a balanced ration we must add to it expensive concentrated foods, such as bran, oil cake, or other grain products.

By increasing the percentage of protein in the fodder or silage a less amount of the expensive grain foods will be required, and, the ration being cheaper, will leave a larger margin of profit. But of even greater importance is the breeding up of the nitrogen content in clover, cowpeas, alfalfa, and other plants which gather nitrogen from the air. These crops should not only have their nitrogen content increased, but they should also be so bred as to succeed far better than now and under far wider ranges of conditions. Red clover, for instance, has been improved comparatively little since it was brought from Europe. It thrives well under some conditions, yet it does not meet all the difficulties and is not profitable in some localities where it should be made very useful. If it could be grown under conditions where it is not now hardy, its use as a fertilizing agent would be greatly extended, and if it were bred to extract still larger amounts of nitrogen from the air, it would be more valuable as a fertilizer and also as a food for domestic animals. Mr. W. T. Swingle proposes that the nitrogen-gathering bacteria associated with the nodules on the clover roots could also be bred so as to be more actively useful; and since brewers have successfully bred special varieties of brewing yeast for making beers of different qualities, the breeding of these bacteria would seem also to be a practical undertaking. The field pea, likewise, is a crop worthy of most serious effort, both that varieties may be secured which will produce profitable crops in localities where it is not now successfully grown, and that the contents of its seeds and its vines and leaves may have a larger percentage of this most valuable element, protein. Alfalfa, cowpeas, and soy beans, for like reasons, should be improved. These are the five principal nitrogen-producing plants of this country, each with its special very large field of usefulness. To change each plant so that its range of successful production would be enlarged 10 per cent, its protein content increased 10 per cent, and its yield increased 10 per cent where now grown, would cost only a very small fraction of the resulting increase in value. Increasing the protein content in this manner would in the aggregate be a very large increase of the nitrogen annually gathered from the air into the soil of the country. Since the sugar content in sugar beets has been so greatly increased, an increase of the protein of clover from 15 per cent of the dry matter to 16.5 per cent or even to 20 per cent should not be impracticable. But, important as may be the increase in nitrogen, breeding so as to adapt these crops to conditions where they now partially or wholly fail, and increasing their general yield and other good qualities in localities where they are now used, are the more important problems and probably should receive the first attention.

There is no reason why the nitrogen content of a variety can not be increased as well as the sugar content, the flavor, the hardiness, the height, or any other measurable characteristic. The Kansas experiment station found that ears of corn of a variety grown for thirty years on the same farm varied in protein content from 9 to 13 per cent, and that different varieties of corn varied about the same. Professor Hopkins, of the Illinois station, proved that corn plants with grain high in percentage of nitrogen generally produced grain with more nitrogen, thus proving that this quality can be improved, and he showed that something can be done at making the selections by mere inspection and without chemical analyses, though chemical analysis is a great aid. Those kernels which showed the largest proportion of dark reddish to white starchy interior, when cut across, as with a knife, had the highest percentage of nitrogen, thus enabling the careful farmer to select for more nitrogen.

ILLUSTRATIONS OF WORK IN PLANT BREEDING.

No attempt can be made here to go into the minute details of breeding the many species of economic plants. The discussion of wheat, corn, timothy, potatoes, apples, black walnuts, and flax in future pages serves to illustrate many of the general methods. Those who wish to engage in the breeding of any plant should first study that plant, paying special attention to its floral organs and to its method of pollination, to the methods of propagating and cultivating it, to the conditions under which it is to be grown, and to the purposes for which it is or might be used.

The literature will not be found extensive nor explicit in most lines, but by applying to his State experiment station, to the national Department of Agriculture, and to persons who have bred the plant concerning which knowledge is desired, the plant breeder can secure valuable information. The discussion which follows, besides showing present plans and results, is meant to be suggestive in relation to plans for breeding many other crops for which the experimenter must develop methods.

BREEDING WHEAT.

The breeding of wheat should not be confined to the few very best wheats, but a fairly large number of varieties may be profitably used, especially in forming new varieties by hybridizing. The best of these, if not all, should be placed under systematic field tests to determine their relative value, and to establish standards with which to compare newly originated varieties.

IMPROVEMENT BY SELECTION ALONE.

In nearly all cases wheat flowers are fertilized with their own pollen, and, in order that the occasional plants which have hereditary power of special value may be secured, it is necessary to plant large numbers of seeds in such a manner that each plant will have an opportunity equal to that given each other plant. At the Minnesota experiment station this is accomplished in the following manner: Twenty-five hundred good kernels of spring wheat are chosen from the bulk wheat of a good variety, either old or newly formed. These seeds are planted in hills 4 inches apart each way (5 inches for winter wheat), one seed in a hill. A dibble may be used to make the holes for the seeds, and the grains may be inserted and covered by hand. To get the hills the proper distance apart each way a large frame is used (see Pl. II, fig. 2). The long boards at the sides of the plot, or series of plots, have nails driven 4 inches apart on their inner edges, and the movable board has marks 4 inches apart across its front edge. When one row is planted the board is moved forward 4 inches to the next pair of nails. The series when planted appears as in figure 13. The dark circles represent plants which are to be removed immediately before harvest, as those shown on the border adjacent to the alleys have a larger food supply than those in the interior of the plot, and must therefore be removed before choosing the best ripe plants. Every individual plant has its number, and whatever notes are made concerning it are entered under that number. Alleys a foot or more in width are left between the series of plots that attendants may have a place to walk in planting, weeding, and harvesting the plants.

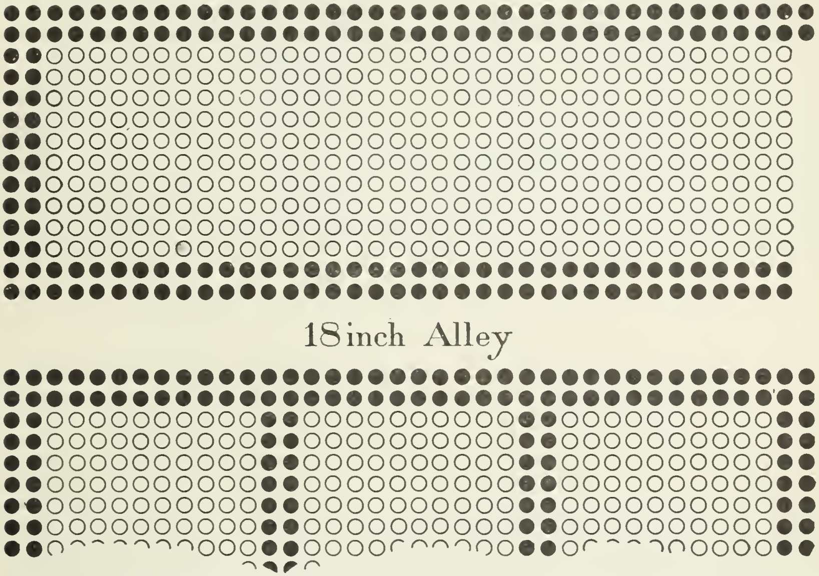


FIG. 13.—Scheme of planting wheat in field crop nursery. Light circles represent plants of the variety under experimentation. Dark circles represent another kind of wheat separating the plots from the alleys, or from each other.

Where a small number of plants is placed in a plot, this is separated from the adjacent plot of the series by a different variety of wheat, as shown by the rows of dark circles crossing the lower series in figure 13. Great care is used in preparing the plot to have the soil uniform, and to so arrange the ditches in the alleys that surface water will not run over the plots. The weeds are kept carefully removed by hand, and early in the season the soil is kept loose by stirring it with a very small hand hoe.

A new machine has recently been devised by the Minnesota experiment station for doing this planting. One to three seeds are planted in each hill, and when a few inches high all the plants but one per hill are destroyed. It is used for other crops also.

Harvesting and selecting the nursery-grown wheat is almost entirely a matter of elimination. A careful man removes from the plot about 95 per cent of the plants, leaving the comparatively few strongest and most desirable plants. In Plate III, figure 1, are shown two plots which contained 100 plants each From the one on the right 90 have been removed, leaving the 10 best standing. The spikes are cut from each plant separately and preserved in a packet or envelope. Where desired, the straw from each plant also may be harvested separately and placed in an envelope by itself; or, if thoroughly dry, it can be weighed at once. Where the variety has too weak straw, causing the crop to lodge, or where the straw is of little value as compared with the grain, the height, the weight, and the ability of the straw of each plant to stand erect are desired, that plants may be chosen which will increase the proportion of grain to straw.

When dry the contents of the packets are weighed. All the plants which are low in weight are at once discarded, even before shelling, reducing the labor of shelling to the few best. The shelled grain having been weighed to get the net weight, the grade or quality determined, and any other notes of interest made, the breeder is in position to make choice of the best plants. One hundred, more or less, of the seeds from each of these few chosen plants are planted in separate nursery plots in the wheat-breeding nursery the second season in a manner similar to that under which the seed was grown the first season. These collections of plants are called "centgeners," this word having been originated to mean a hundred plants, more or less, springing from the seeds of a single mother plant—that is, a large number of one generation. Each group of plants from a single mother plant thus planted in a centgener plat is given a nursery-stock number, written thus: "Nursery stock No. 17, 1892," this serving as a name for this stock so long as it is in the nursery. In case any stock becomes especially prominent in the wheat nursery, all or part of its seed is transferred to the field trials, where it is given a Minnesota number, as "Minnesota, No. 163, wheat." The nursery stock number, the class name of the parent wheat, also its Minnesota number, and any facts regarding its history, are entered upon a blank card, called "Introductory Sheet," which is placed as the first card in the history of the nursery wheats. The form of this sheet is as follows:

SELECTED STOCK—INTRODUCTORY SHEET.

(Minn. Form 61.)

WHEAT: Class name of parent stock, ——. Nursery stock No., ——. Minn. No. of parent stock, ——.

Date, ——, —.

Origin and history of parent stock:

Size, 5½ by 8½ inches; color of card, white.

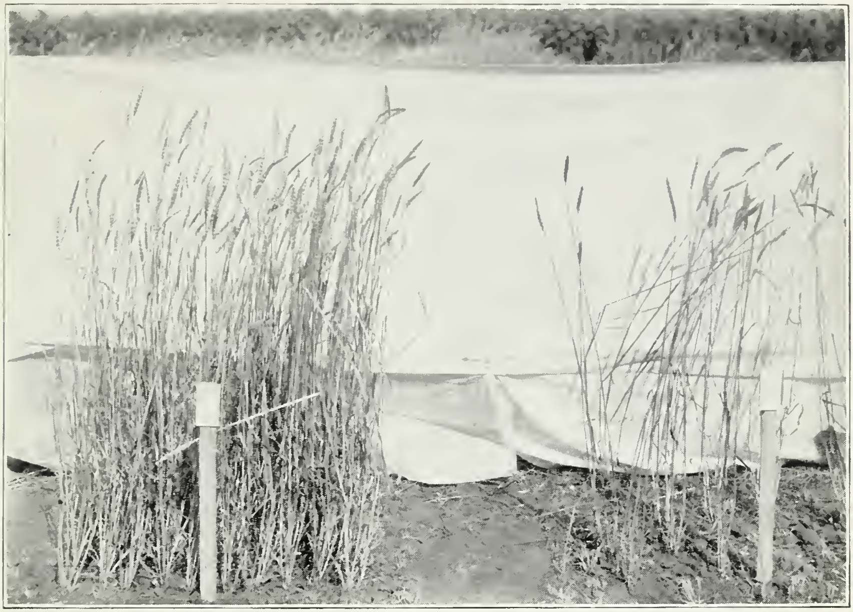


FIG. 1.—TWO CENTGENER PLOTS OF WHEAT.

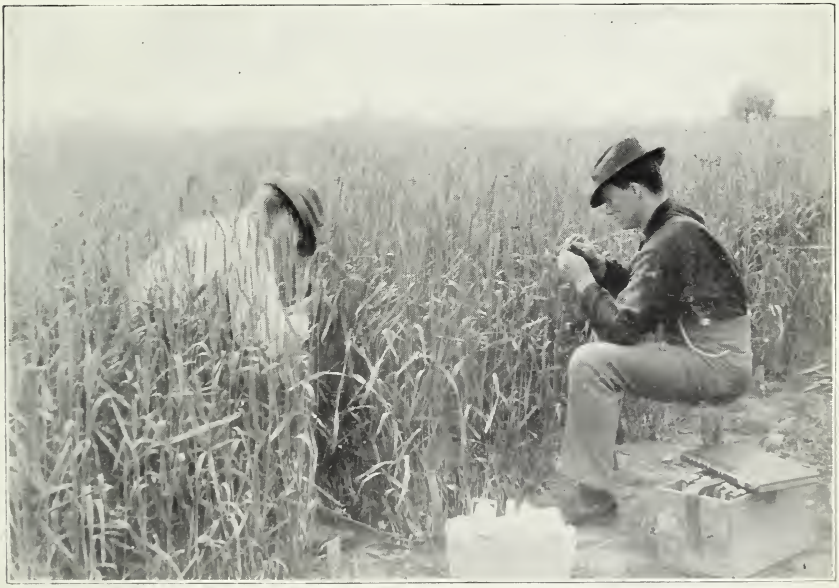


FIG. 2.—MEN EMASCULATING AND CROSS-POLLINATING WHEAT.

When the plants are ripe, notes are taken as to the relative size and strength of each plot. Each plant in the plot is pulled, counted, and placed in a bundle, and a choice spike is taken from each of several of the best plants that the best seed may be available to plant a centgener of this stock the next year. With a newly devised thrashing machine and a specially arranged fanning mill (Plate IV. fig. 2), which save every kernel from these small plots, the bundle is thrashed, cleaned, weighed, graded, and may then be analyzed for nitrogen. To the weight of this bulk grain is added that of the grain saved in the packet for planting the third year. This total weight is divided by the number of plants actually harvested, thus securing the average weight per plant of the progeny. The third and fourth years, a centgener is similarly planted, harvested, and tested. The records are kept on blanks in the following form:

YEARLY HISTORY SHEET.

(Minn. Form 63.)

Wheat: Class name ——. Nursery stock No. ——. From plant No. ——. Date ——. Cent. No. ——. Date ——.

CENTGENER NOTES.

Days maturing.	No. seeds planted.	Type.	Height.	Strength.	Stiffness.	Rust resistance.	Smut.	No. plants harvested.	Av. yield.		Nitrogen.	Note.
									Straw.	Grain.		

NOTES ON SELECTED PLANTS.

Nursery No.	Days maturing.	Height.	Stiffness.	Rust resistance.	Spikes.			Chaff.				Berry.					Yield of straw.	Yield of grain.
					No.	Length.	Missing.	Color.	Smooth or hairy.	Bearded or awnless.	Holds %.	Color.	Size.	Plumpness.	Condition of bran.	Grade.		

Size of card, 5¼ by 8¼ inches; color of card, white.

At the end of three years the data recorded in the yearly history sheets are collected and averaged for each stock, using the following form:

SUMMARY SHEET—CENTGENER NOTES.

(Minn. Form 65.)

WHEAT: Nursery stock No. ——.

Year.	Date planted.	No. seeds planted.	Type.	Height.	Strength.	Stiffness.	Rust resistance.	Smut.	No. plants harvested.	Av. yield.		Nitrogen.	Note.
										Straw.	Grain.		

Size of card, 5½ by 8½ inches; color of card, pink.

Then the averages for the various stocks—the progeny of the single mother plants, respectively—are compared by collecting them on such a blank as the following:

GRAND SUMMARY—CENTGENER NOTES.

(Minn. Form 67.)

WHEAT.

Nursery stock No.	Date planted.	No. seeds planted.	Type.	Height.	Strength.	Stiffness.	Rust resistance.	Smut.	No. plants harvested.	Av. yield.		Nitrogen.	Note.
										Straw.	Grain.		

Size of card, 5½ by 8½ inches; color of card, blue.

Thus the breeding ability—centgener power—of the various mother plants is tested and compared as to yield, grade (upon inspection), and percentage of nitrogenous content of the grain, and as to ability of the plant to stand erect, resist rust, etc.

The records of hybrid nursery stocks are in like manner kept on these cards. On the uppermost card are placed the facts concerning the two parent varieties and the objects sought in the cross. On the second card may be recorded the facts about each individual plant produced the second year by cross-pollinating a certain wheat spike. After having been grown for a few years to allow of free variation the hybrid stocks are dealt with year by year much as in the case of selected

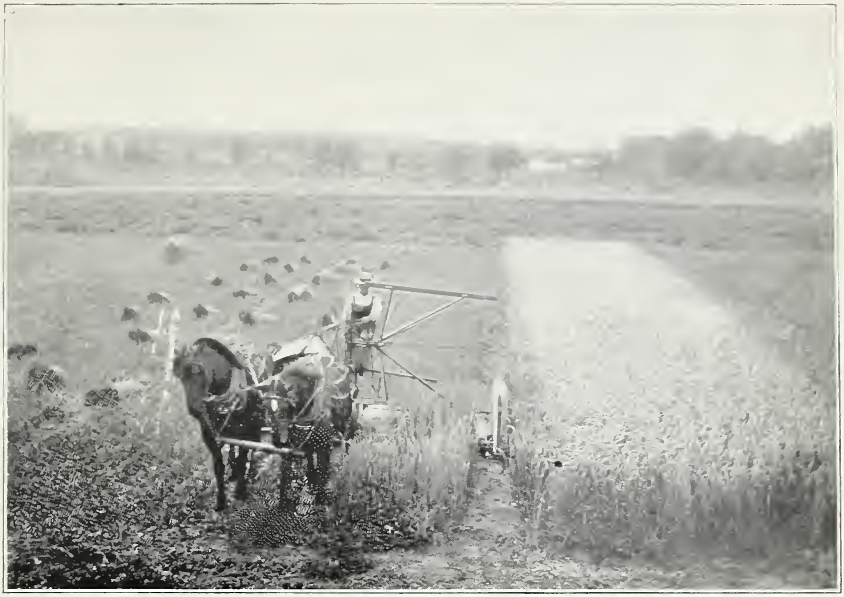


FIG. 1.—HARVESTING TWENTIETH-ACRE PLOTS OF WHEAT.

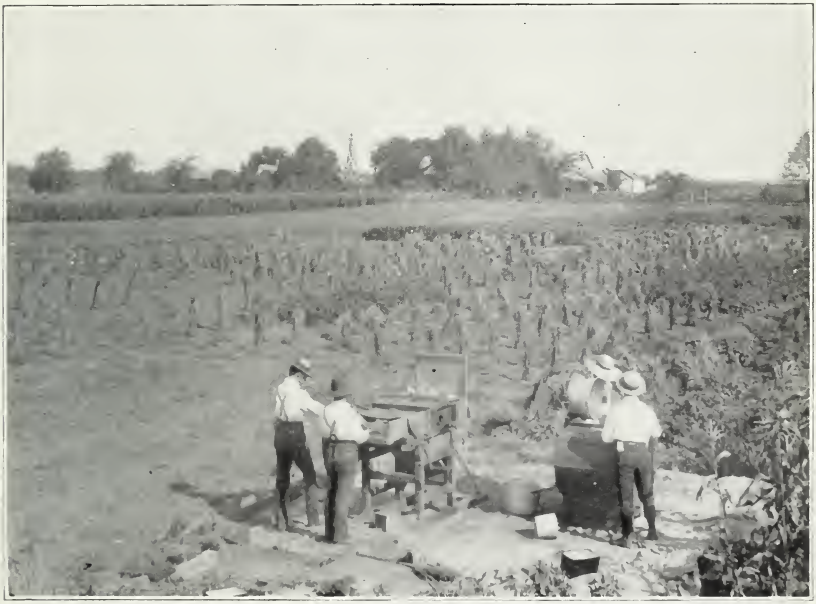


FIG. 2.—THRASHING AND CLEANING WHEAT FROM CENTGENER PLOTS.

stocks, and the same cards for the yearly records and the summaries are used as described above (see fig. 14).

At the end of the fourth year, when three annual centgener trials are averaged, all but the best stocks are eliminated. The seeds of those which have distinguished themselves are increased during the fifth year, and they are planted in uniform field-test plots in the sixth, seventh, and eighth years. The yields per acre, the grades, etc., are now averaged, and those which here distinguish themselves for yield, grade, etc., are given duplicated milling, baking (Pls. I and V), and chemical tests to thoroughly determine their real value to the miller and to the consumer as well as to the farmer. Some which prove second best, as well as those which prove worthy of immediate dissemination to the farmers, are sent to the substations within the State and to experiment stations in adjoining States in payment for similar favors from them, since it has been found that a wheat which is best in one locality is often not best in another locality. Once a new wheat has won its place as having yielded more value per acre at any experiment farm than the commonly grown varieties, its quantity is rapidly increased, and it is distributed to the farmers of the State or district, at current prices for seed wheat. Each farmer who receives this wheat is given a certificate of its genuineness as being the stock which made certain yields in comparison with the other wheats on trial at the experiment station. The farmer is requested to make reports of the yield and other qualities as compared with the wheat he is commonly growing on his farm, and he is expected to sell his first crops at remunerative prices to his neighbors for seed. In this way the final and most crucial test is given to a new strain or variety of wheat in each county in the State. The amount sent to each farmer is limited to a few bushels, and an effort is made to distribute each new kind to several farmers in each county in which it is likely to do

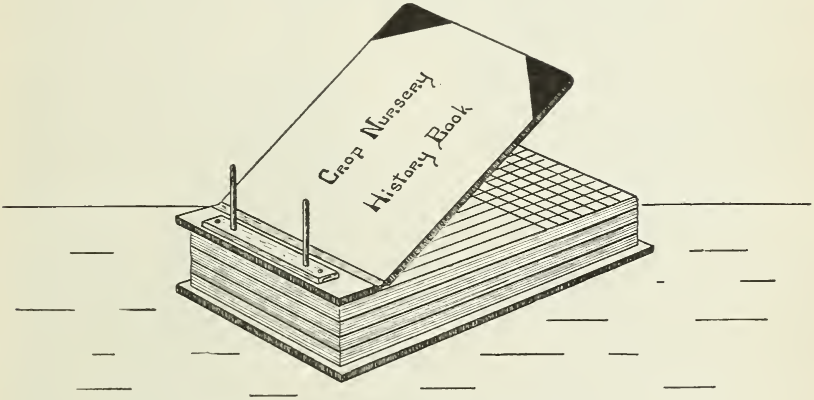


FIG. 14.—Method of preserving record sheets.

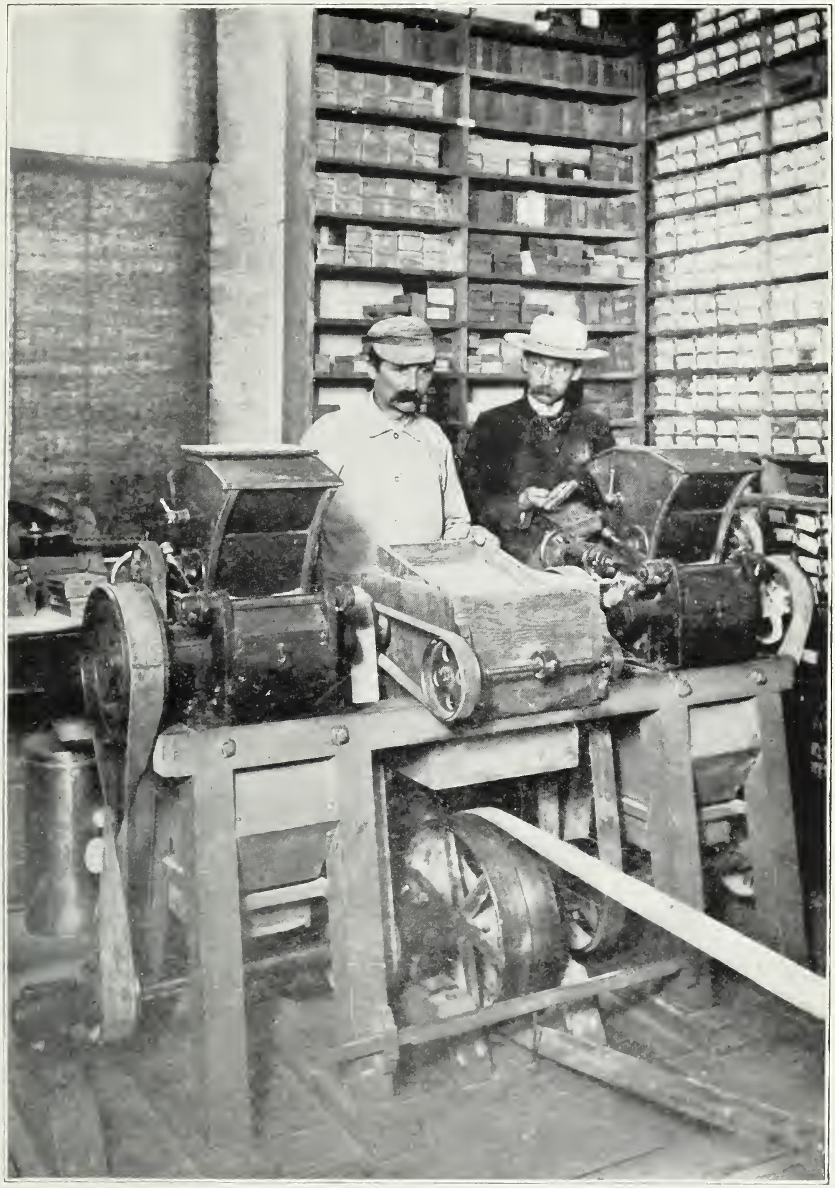
well. Without dissemination under some such system as the above, experiment stations would hardly be justified in breeding many of the staple crops, since only through successful methods of distribution do the farmers of the State receive any benefit.

WHEAT FLOWERS.

The floret is the most interesting part of the wheat plant. Figure 15 shows the separate parts of the flower, also the spike and the seeds. The floral plan is shown by the cross section at *5*, where the flowering glume (*fg*) and the palea (*p*) are folded about the three anthers (*a*) and the stigma (*s*). Before the flower is mature the anthers are closely packed about the stigma in the bottom of the floral cavity, as shown in *4A*. At the maturity of the flowers the anthers are shoved upward, some of them passing out of the floret, as at *4B*. The floret usually opens about dawn, and closes again within an hour. This is shown in figure 16, where the opening of the anthers is also illustrated, as shown in *4B* (fig. 15). In passing upward the pollen sacs break open, and before the anthers reach the outside of the floret some pollen falls back on the stigma. As the floret matures the stigma changes from its folded form, as shown at *12* (fig. 15), and expands into a plume (*13*). The pollen grain is a minute round male cell (*11*, fig. 15), which, falling upon one of the minute branches of the stigma (*13*), "germinates" and sends a tube into its tissues (*18*). This pollen tube, growing downward, enters the ovary (*13 o*), where its nucleus fuses with the female nucleus in the ovum, and from this fusion the embryo of a new plant arises. The stigma, having served its purpose, withers, while the ovary begins developing (*14. s* and *o*), and in a few weeks a mature seed fills the floral cavity. The seed has a ventral and a dorsal side, as shown in *15*, *16*, and *17*. At the bottom on the dorsal side is the germ, sometimes called "chit," the miniature plant, which is ready when planted tc use the remaining portions of the kernel. the endosperm, as food while it sends leaves into the air and roots into the soil, establishing itself so that it can grow into a useful plant, multiplying itself many fold.

FORMATION OF VARIETIES BY HYBRIDIZING.

Hybridizing is used to produce plants with greater tendency to variation. Hybrids are made between numerous varieties of wheat, and in each case large numbers of florets are handled. Great care is exercised to secure superior plants of the varieties hybridized, and as a rule plants are chosen from the best centgener stocks which are under improvement by selection from the most useful standard parent wheats, as mentioned above. In preparing a good spike of wheat for hybridizing, all but one or two dozen strong florets in the center of the spike are removed by means of sharp scissors, as shown in figure 17. (See also Pl. III, fig. 2.) The anthers are removed from these



MILLING SAMPLES OF WHEAT.

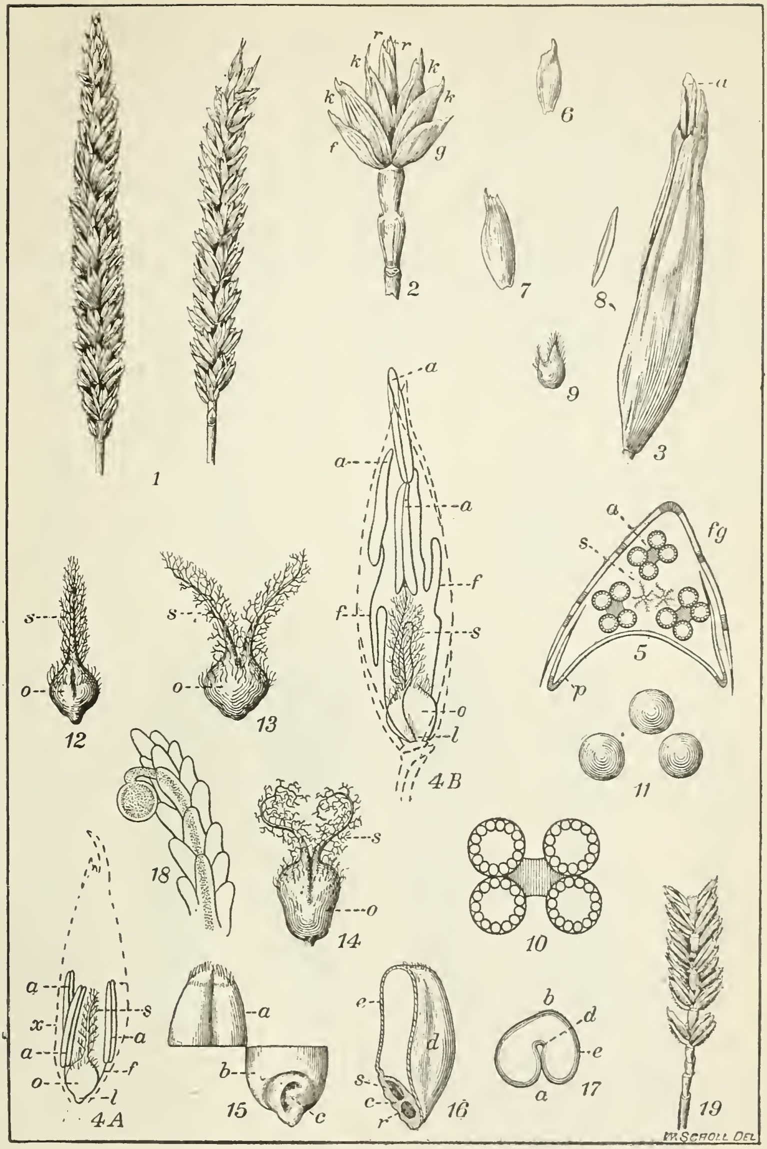


FIG. 15.—The spikes, flowers, and seed of wheat. *1*, spike of Fife at the right, and a blue stem spike at tho left. *2*, spikelet (natural size), with a few joints of the rachis; *f* and *g* are flowerless glumes; *k*, florets bearing seeds; *r*, rudimentary florets. *3*, a single flower closed, just after flowering (×5). *4A*, longitudinal diagram before flowering; anthers marked *a*; ovary, *o*; stigma, *s*; filament, *f*. *4B*, diagram of floret just after flowering, showing how anthers are held within envelope, lettered as in *4A* (×5). *5*, transverse diagrammatic section or floral plan, as is made by cutting across *4A* at X; *fg*, flowering glume; *p*, palea; *a*, anthers; *s*, stigma. *6*, flowerless glume (natural size). *7*, flowering glume (natural size). *8*, palea (natural size). *9*, lodicule (×4); shown also at *l* in *4B*. *10*, cross section of anther, showing the pollen sacs and the central mass of tissue to which they are attached (×30). *11*, pollen grains, round and smooth, 55 micro-millimeters in diameter. *12*, ovary and stigma just prior to flowering. *13*, at the time of flowering. *14*, shortly after flowering. *15*, *16*, and *17*, the mature seed; *a*, the ventral side; *b*, the dorsal side; *c*, the germ, or chit; *s*, the stem end of the germ; *r*, the root end of the germ; *e*, outer layers of the grain, or bran; *d*, the incurved surface of bran on the ventral side of the seed. The white portions of *16* and *17* are the floury interior, consisting of cells containing the gluten and starch from which white flour is made. *18*, portion of the stigma, showing an attached pollen grain which is germinating and sending its tube down to the ovule. *19*, spike from which small late flowers have been removed preparatory to crossing.

remaining florets, as shown in figure 18, this being done when the flower is yet young and the anthers green or only slightly tinged with yellow. The emasculated spike is covered by wrapping about it a piece of tissue paper, tying above and below to prevent the accidental introduction of foreign pollen. One or two days later, when the flowers are fully developed, as shown by the opening of flowers of the same age on neighboring spikes, pollen is brought from the variety chosen for the male parent and inserted into the emasculated florets. The cross-pollinated spike is again covered with the paper, to keep out other pollen. The several resulting grains from each handled spike are stored in a packet and so planted the second year that the plant resulting from each seed has its individual plant number in the nursery. The entire product of each plant is harvested, and full

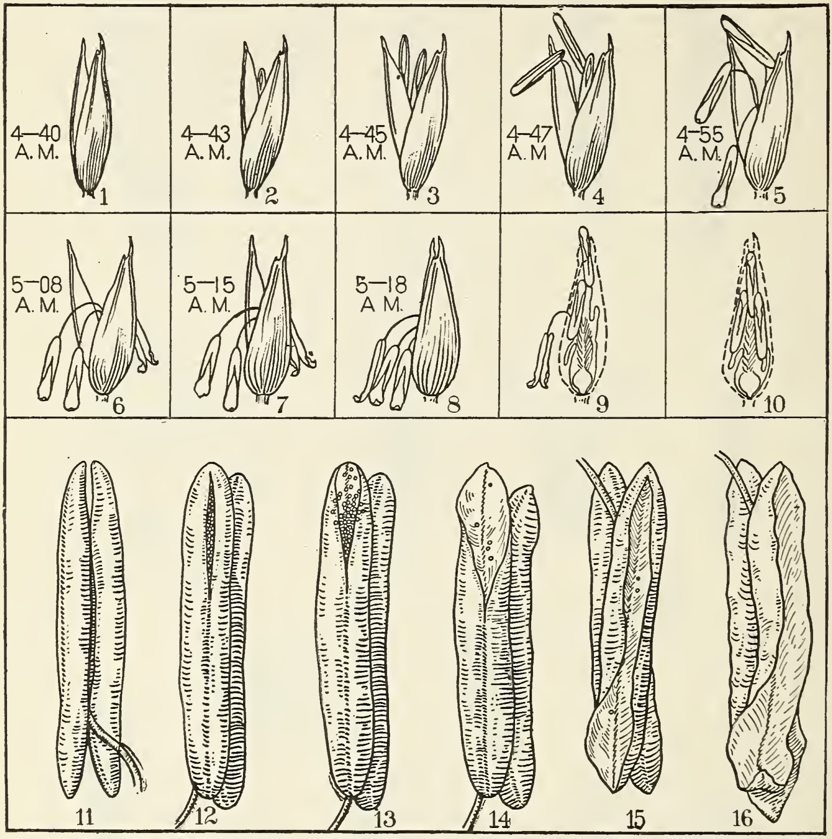


FIG. 16.—Opening of wheat flowers and anthers. *1* to *5*, opening of a wheat flower; *6* to *8*, closing of same; *9*, closed flowers, with one anther hanging out; *10*, wheat flower entirely closed; *11*, the anther, with its attachment to the filament; *12* to *16*, the progressive changes in the opening of the pollen sacs; *15*, *16*, anthers which have fallen out from the flower, thus inverting their position and allowing the remaining pollen to fall out, the anther becoming shriveled and brown.

notes are taken on the plant and on the seed. One of three general methods may now be used:

Method No. 1.—Each hybrid seed is separately planted the second year. The third year a centgener is planted from each original hybrid plant of the second year, and from among the plants of this centgener are chosen superior plants for mothers of centgeners the fourth year. The fifth year, variation having largely spent its force, centgeners can be grown and tested as under the plans given on pages 44 to 49, inclusive.

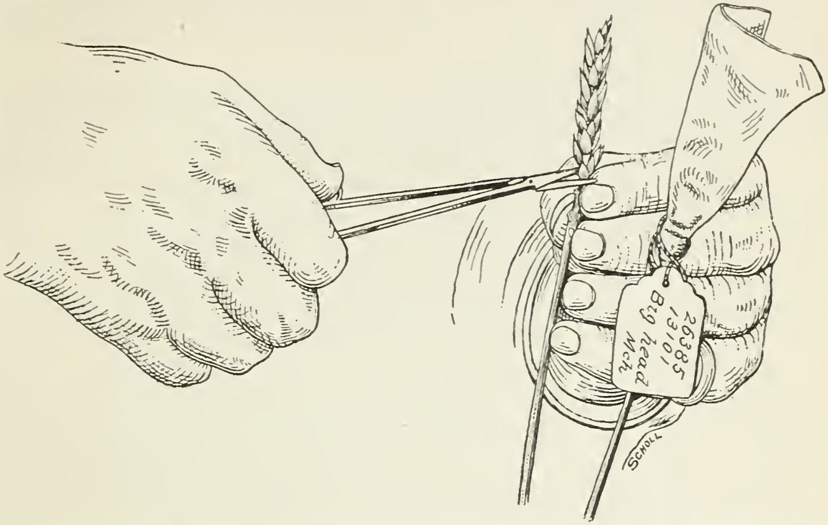


FIG. 17.—Removing the flowers of the smaller later spikelets at the end and at the upper base of the spike, leaving only the strongest florets to be emasculated and supplied with pollen from another plant. In front of the operator's left hand is a spike which has been cross pollinated, then covered by wrapping about it a piece of tissue paper, which is tied on.

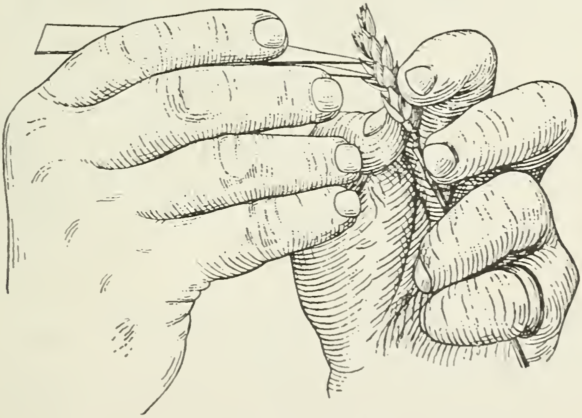


FIG. 18.—Opening the florets to remove the anthers.

Method No. 2.—Each hybrid seed is separately planted the second year. A nursery centgener plot is planted the third year from the seeds of each strong plant of the second year, and several of the best yielding plants of each promising type are saved for mothers and mixed together, to be used as nursery stocks, planted in a large nursery plot the fourth year, and treated in centgenet and field trials as described on pages 44 to 49.

Method No. 3.—All the seeds of a hybrid between two stocks, or plants, or spikes, as the case may be, are planted in a nursery plot the second year, and the resulting crop of seeds is mixed together and planted in drills or broadcast the third year, and again the fourth year. By this time the "reactions" have mostly developed. The fifth year 2,500 hills, 4 by 4 inches apart, are planted, and thinned to one plant in a hill. These plants are then used the same as foundation stocks of standard wheats, as stated on page 44, the hybridizing having given wider variation, increasing the opportunity to select superior mother plants.

Method No. 3 seems the most simple and the most comprehensive. It may be wise in many cases to mix together two or more closely related nursery stocks for use in the field tests and later used by farmers, avoiding any possible danger of founding a variety upon the blood of a single mother plant.

EXPERIMENTS IN WHEAT BREEDING.

The actual formation of superior varieties, which at an early date will "make two blades of grass grow where one grew before," is of immense value, but of immeasurable importance would be the fullest knowledge of how best to breed into each and every species of useful plants and of animals those qualities which make them more useful in supporting and giving pleasure to humanity. Enumerating some of the lines of experimenting on the theory of wheat breeding in progress at the Minnesota experiment station may suggest similar studies by other experimenters with the various plants upon which the respective States depend for a large proportion of our country's wealth. The numbers at the left refer only to the station records. The statements in parentheses under the respective experiments are brief statements of results to date:

IV. 2. Seeds compared from heavy *vs.* light-yielding spikes.
(Results to date show that the breeder should choose the heavy-yielding spikes as well as heavy-yielding plants.)

IV. 3. How to select wheat plants for greater ability to stand erect.
(The centgener plan of experimenting is aiding in the solution of this important problem. The tendency in the blood of a mother plant to beget a race with stiff straw can not well be judged with the single plant, but it can with the small plot of a hundred or more of the progeny.)

IV. 4. Methods of developing earliness.
(By hybridizing and using centgener plot selection.)

IV. 6. Making better varieties by improving each of two stocks by selection *vs.* first hybridizing the two varieties, and then selecting.

(Recent results from incrosses and outcrosses lead to the belief that hybridizing is of paramount importance to supply the best stocks for the more laborious work of selection.)

IV. 8. Time required to reduce hybrid types to good yield, then to uniformity of type.

(Hybrid wheats vary as to the length of time variation continues under rigid nursery selection, but generally they are reduced to a type in a few generations, this being accomplished with little special effort while selecting for superior yield and other qualities.)

IV. 10. Study of best methods of planting field-crop nursery.

(Important modifications of the plan of breeding annually result from these experiments.)

IV. 12. Comparison of yield of crop from large-yielding plants with crop from poor-yielding plants.

(The selection of large-yielding individual wheat plants is important as a means of securing strong plants to be tested in centgener trials to determine their power of producing plants with large average yield.)

IV. 15. Does crossing and hybridizing increase variation?

(Many results show this very plainly in numerous characteristics, both those of botanical interest and of economic value, as yield, percentage of protein, etc.)

IV. 17. Method of breeding for strong chaff, which prevents easy shelling.

(By means of hybridizing and centgener-plot selection, good results are promised.)

IV. 22. Breeding wheats for special soils.

(Extensive trials of new and old wheats show conclusively that wheats must be especially bred for each of several conditions in Minnesota, as well as for each of the several adjoining States.)

IV. 23. Effect of changing seed wheat from one locality to another.

(The change in the new crop of seed is marked: sometimes for the better, often for the worse. General facts for practice are not yet available.)

IV. 27. Methods of seeking the best plants in the centgener or in the large nursery plot of stock seed.

(By inspection, the choice of 5 per cent of the best-appearing plants nearly always includes the plant which gives the largest weight and superior grade of grain.)

IV. 28. Does environment modify the individual, and are acquired characters transmitted?

IV. 29. How much do wheats cross in nature?

(Natural crosses do occasionally occur: percentage of such has not yet been determined, but it is very small.)

IV. 30. Methods to use in breeding for rust resistance.

(Records on the rust resistance of 100 progeny of each of numerous parent plants, made in percentages, promise to aid materially in finding blood lines which resist rust within the standard variety and among the plants of the new hybrid.)

IV. 35. Vigor of parents *vs.* the vigor of progeny of different degrees of relationship.

IV. 36. Should plants adjoining blank hills be thrown out in nursery selection and in scientific nursery studies of variation, etc.?

(One or two blank hills have so little effect on the yield of adjoining plants, where the hills are 4 by 4 inches apart, that in selection to form new varieties no heed need be taken of them. In the study of scientific questions, however, two or three grains should be planted in each hill, and early thinned to one plant, that the stand may be complete, giving to all plants an equal chance.)

IV. 37. Making a strain or variety of wheat from a single mother plant *vs.* from several mother plants.

(The comparison is not completed. But numerous strains, each from a single mother plant, have been grown for eight years in field-test plots, and they continue to average as much superior to the parent variety as at first, showing, so far, no signs of deterioration.)

IV. 38. Distance apart for wheat plants in the field-crop nursery.

(Four inches apart each way for spring varieties and 5 inches apart for winter varieties have proved the most satisfactory.)

IV. 39. Methods of handling the spike in cross-pollinating wheat.

(The best of several methods tried is as follows: Remove the smaller upper and lower spikelets and the smaller florets on the central spikelets, leaving ten to twenty of the best. Emasculate these early, about the time the first tinge of yellow appears in the anthers. Cover the spike with tissue paper. Twenty-four to forty-eight hours later, when the florets on neighboring spikes of similar age are opening, bring pollen from the plant chosen for the male parent and, removing the covering, apply pollen to each floret.)

IV. 42. Methods for treatment of hybrids during the first several years.

(One conclusion is that wheat hybrids should be grown in quantity during the first three to five years, that variation may have its full opportunity; then the selection of superior plants should be from among large numbers, as from among several thousand in the nursery plots.)

IV. 49. Crop from mother plants with low percentage of nitrogen *vs.* crop from mother plants with high percentage of nitrogen.

IV. 69. Should the plants in the wheat nursery be fed heavily, medium, or lightly in seeking plants best adapted to heavy yield in the ordinary field?

HYBRIDIZING AS A CAUSE OF VARIATION IN WHEAT.

In Plate VI (fig. 1) are shown spikes of two parent wheats, and between them an average spike of their hybrid progeny, as selected in 1895 by Mr. Warren W. Pendergast from the hybrid wheats at the Minnesota experiment station. In the upper row the right-hand spike is the Blue Stem parent, the left-hand one the Fife parent, and the central spike is the average spike of the single hybrid plant of the first generation. The spikes in the middle and lower rows are forms which appeared in the 100 plants of the second generation, all of which came from seeds from the single plant of the previous year. The "reaction" here was unusually strong, and the types of wheat produced are neither like the two parent plants nor yet intermediate between them, but several are very much like various of the so-called "species" of wheat. Henry Vilmorin, of France, showed the writer most of the so-called "botanical" classes of wheat growing in his garden, all of which were produced by hybridizing two varieties. He believed that this is proof "that all the domesticated wheats originated from a single species." It certainly indicates blood relationships between the classes of wheats. Whether this is wholly the result of

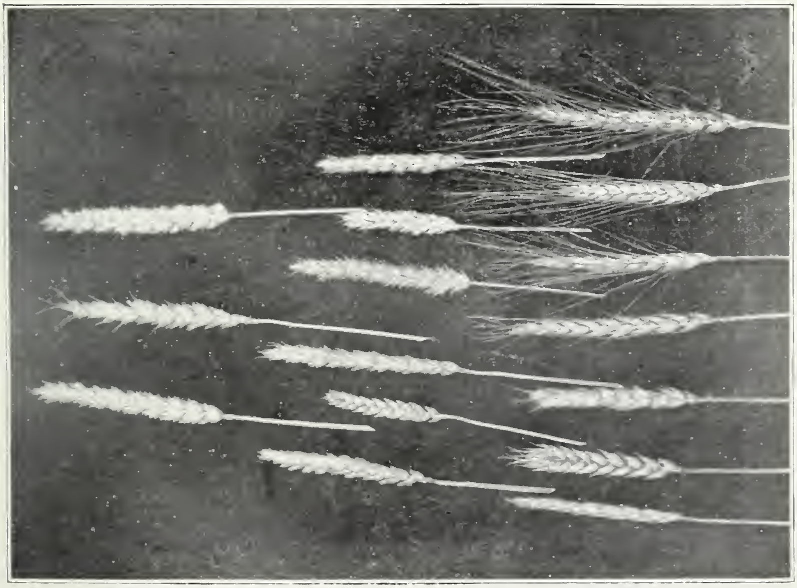


FIG. 1.—SPIKES OF PARENT AND HYBRID WHEATS.

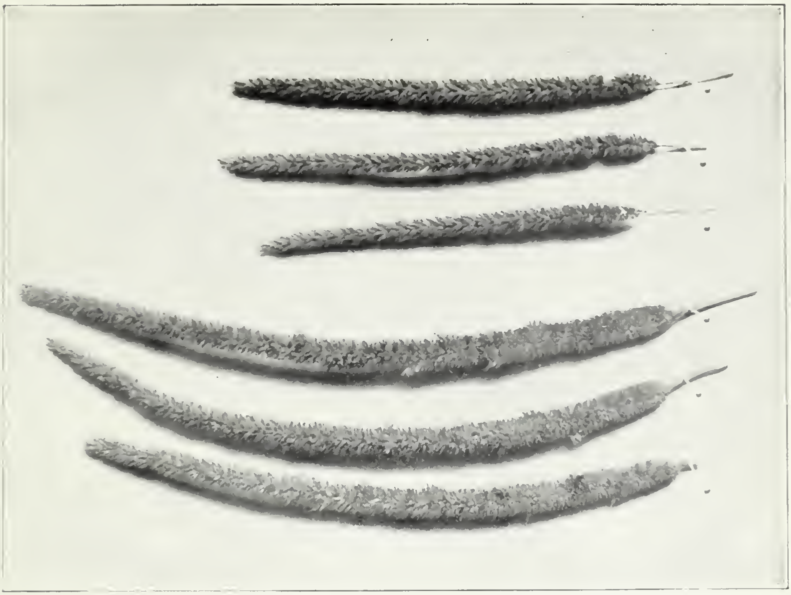


FIG. 2.—SPIKES OF TIMOTHY, SHOWING IMPROVEMENT BY SELECTION.

the differentiation of a single original species into subspecies, races, and varieties, or whether it is in part due to hybridizing between original species, may be questioned. It is also a remarkable illustration of the intricate relationships existing in nature even among plants apparently exclusively self-fertilized.

In figures 2 to 7, inclusive, with accompanying text and notes, the fact of the creation of variation in yield of wheat plants by hybridizing is also illustrated.

In 1893, from a floret of Blue Stem wheat pollinated from a Fife plant there resulted a seed which in 1894 developed into a plant, No. 1814 in figure 19. In 1895 a centgener of plants was grown from the 1894 mother plant. Of these, 30 per cent had smooth chaff, resembling the Fife parent, and 70 per cent had hairy, velvety chaff, resembling the Blue Stem parent. In the succeeding years smooth-chaffed plants were chosen for mother plants from one stock selected for the development of a smooth-chaffed variety, and plants with velvety chaff were chosen as mother plants from another stock selected for the development of a hairy-chaffed variety.

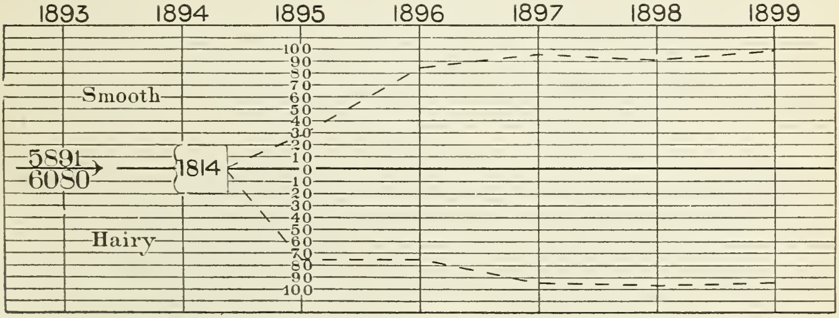


FIG. 19.—Graphic expression of the results of an experiment in developing from a single hybrid plant, No. 1814 (produced by crossing a plant of Fife with one of Blue Stem) two varieties, one having smooth and the other hairy chaff.

In figure 19 it is shown graphically that in the third generation each was nearly true to type, and that it remained practically true to type. Other hybrids under experiment are not all reduced to type so rapidly, as plants vary greatly in their tendency to continue departing from type; but if hybrid plants can thus easily be reduced to type in regard to largeness of yield, content of nitrogen, etc., and afterwards or simultaneously be in like manner easily made uniform in appearance, the improvement of wheat by cross breeding will not appear very difficult.

BREEDING CORN.

Corn breeding illustrates some of the principles of practice applicable to species which in nature are open-pollinated. Since the male and female flowers are on separate portions of the plant, the female florets are more often fertilized by pollen from neighboring plants than by pollen from the tassel of the same plant, and the individual plants of corn, being of mixed blood, vary greatly. Corn is easily improved, selection and hybridizing being easily and very effectively applied in making new varieties which will suit definite conditions. The careful selection of seed in the field by our farmers is changing corn for the better very rapidly. Experiment stations, seed firms, or farmers who wish to enter upon more careful corn breeding, so as to get better and more rapid results than usual, will find the following plans helpful.

SELECTING SEED CORN.

The first selection of corn is made from the field containing the varieties chosen for foundation stock. Since the plant is the unit in breeding, ears are chosen from each of several hundred of the best plants, and the shelled corn yielded by the plant is weighed. Where practicable, nitrogen determinations of the grain from each plant may be made, so as to eliminate in this first selection all those mother plants which are low in their percentage content of protein compounds; or the percentage of nitrogen may be roughly determined by choosing ears in which the grains appear glutinous rather than starchy when cut across.

Seeds from 100, more or less, of the best of these plants should be chosen, and the second year a centgener plot should be planted from each. The centgeners are planted in single rows placed side by side, 100 hills or more in each. The rows are planted 3½ feet apart, with the hills a foot or more apart in the row. Two seeds are planted in each hill, and when the corn is several inches high it is thinned to one plant in the hill, thus providing each plant with the same room as each other plant. At this point one of several plans may be followed.

Plan No. 1.—When mature, all plants of each centgener are harvested and dried, the grain is shelled out, and the grain, cobs, and stalks are separately weighed. These weights are divided by the number of plants actually harvested, to get the average yield of the plants from each mother plant. Notes are made of the characteristics of the plants, as height of ear, height of plant, etc., and an analysis of the mixed grain from all plants gives the yield of nitrogen per plant of each stock; or inspection of the kernels, cut across, showing the proportion of dark nitrogenous to white starchy substances, gives a fair index of the content of protein. Only part of the seed from each mother plant having been required for the centgener tests the previous year, there is an abundance of seeds of each of those mother plants which produced superior centgeners for again planting the third year. By planting the corn nursery the third year to centgeners from these best plants the poorer blood is discarded and the blood of the best mother plants is intermingled. To here further discard undesirable blood, the weaker plants are detasseled just before flowering, thus preventing their pollen falling upon the silks of choice stalks. Several of the best-appearing plants are now chosen from each centgener, and tested as to weight and quality of grain, etc., that the very best may be secured for mothers of centgeners the fourth year. In following years the same plan is pursued. Seed of any stock which has distinguished itself in the nursery can at any time be taken to the field, multiplied, tested beside standard varieties, and, if it there proves superior in yield and quality, distributed to the farmers. Varieties which become prominent in the field may be again introduced into the nursery and subjected to rigid breeding; and while in the field, careful field selection should also be carried on.

Plan No. 2.—A somewhat simpler method is to select superior plants from among the centgeners as grown the first year under Plan No. 1 and at once continue the nursery selection as there described for the succeeding years.

Plan No. 3.—A still simpler plan is to plant and test centengers as in Plan No. 1 and save sufficient seed from the best plants in the best centgeners to plant a field the second year. Careful field selection of seed could then be carried on for one or more years and the plan of first-year centgener selection, as in Plan No. 1, could be repeated by again selecting seed from the field.

Plan No. 4.—Careful field selection may be made effective, as it has the important advantage of very large numbers to select from. When husking the corn from the standing stalks, as is the practice in Iowa and surrounding States, choose ears from many superior plants. By weighing, and by inspecting or analyzing for quality of gluten, eliminate all but the best. In many cases where hand husking has given way to the husking and shredding machines, results in yield of grain per acre may be more rapidly reached by breeding for two-eared dent varieties. Where corn is shocked, to be hand or machine-husked later, the seed should be saved before the corn is cut, while the entire stalk can be observed. In order to get the ears from the best plants it is necessary to husk—or at least to strip back the husks from—five times as many large ears as are to be saved for seed. Where two or more fields are planted to the same variety the choicest seed should be planted in one field and seed chosen from there for the next year's planting.

While it may be practicable to use only one mother plant as the basis of a variety in a close-pollenized species like wheat, this should not be done in a species like corn, which is accustomed to free mixture of parental blood. McClure, in Illinois, found that self-fertilizing in corn caused a loss of vigor, and suspected that self-pollination in the cornfield may be responsible for many of the barren stalks so commonly found in our cornfields.

HYBRIDIZING VARIETIES OF CORN.

In the work of variety formation hybridizing is very useful. Before hybridizing two varieties of corn it is best to carefully select each so as to get mother plants of superior worth. Any one of several simple plans may be pursued in cross-pollinating.

First plan.—Alternate rows of each may be planted and one kind detasseled, so as to insure pollination by the other. Seeds from the resulting ears may be planted for two or three years, that the mixing of blood may continue in the production of variations. From a field of at least an acre of this mixed corn superior plants may then be chosen for planting, as indicated under the plans of selection outlined above.

Second plan.—Seeds of the choice plants of two varieties may be mixed in bulk and planted in the corn nursery, one seed in a hill, as above mentioned, so that mixing may occur naturally. By detasseling or removing all but the best plants before flowering time, only good plants will cross, and the best plants may be chosen for mother plants.

Third plan.—Hybrids may be made by hand pollinating, (a) choosing superior plants in two separate stocks in carefully planted nurseries; (b) choosing plants in a nursery where the two varieties are planted in alternate rows; (c) choosing plants in two ordinary fields, either near together or far removed from each other.

In hand pollinating, cloth bags 10 by 20 inches are used to cover the ear of the plant of one variety and the tassel of the other variety to be crossed. These are slipped on and tied a few days before the flowers mature. The bag on the ear is removed—temporarily protecting the ear from other pollen by an umbrella—and pollen from the bag containing the tassel is dusted upon it. This should be repeated daily for two or more days that the ear may be fully fertilized. The further breeding of the mixed stocks from the hybrid ears thus produced may be done in a variety of ways, but in any case large numbers of plants should be grown for two or three years, that the variations inaugurated by the mixture of the two races of blood may have ample opportunity to go forward. These stocks may be planted in the field for a few years, where a very large number of plants may be used, and from which in the second or third year superior mother plants may be chosen, that their seeds may be taken into the corn nursery for further selection, as already outlined under "Selecting seed corn."

Since the nitrogen determination can now be so cheaply made, it would seem that the breeding of corn with heavier yield and with a higher percentage of nitrogen could be made profitable on an extensive scale. Nitrogen added to our corn crop would be as valuable as sugar to the sugar beet. The addition of nitrogen will no doubt be much slower and more difficult than the addition of sugar, but should amply repay the State or private plant breeders for the expense. Careful notes, records, and pedigree summaries can be worked out for the mother plants and their centgeners of progeny in careful breeding of corn in much the same manner as has been outlined in the breeding of wheat. The yield, the per cent of nitrogen, the size, form, and character of the stalk are individual characters which should be numerically recorded in securing superior parent plants; and in testing these mother plants by comparing large families of their progeny the centgener yield, percentage of nitrogen, etc., should be recorded, averaged, and compared.

Farmers can and do materially improve many of their varieties of corn by crossing and selecting, and in some cases they injure good varieties by injudicious crossing. Once a superior variety is obtained, it should not be allowed to be mixed with another or replaced by another without the best of proof that the change will be for the better.

BREEDING TIMOTHY.

In 1889 the writer gathered seeds from numerous timothy plants found along the wayside and on farms in the neighborhood of the Minnesota experiment station. A hundred or so seeds from each mother plant were planted in a plot, one seed in a hill, the hills being 12 by 18 inches apart. When these plants were 2 years old, each having stooled, making a bunch a foot or more across, the best plants were chosen from the best plots. Seeds from these best plants were harvested and plots were similarly planted, and this process was repeated for succeeding generations. About 50 plants of the third generation were divided up into settings, which were transplanted into plots a square yard in area. When these were 2 years old, seeds were saved from the best plots, and this seed was sown to increase the stock of seed from these varieties. The variations among the plants was sufficient to warrant us in attempting to select some of the stocks as mothers for the development of meadow varieties and others for pasture varieties. The seed has now increased to sufficient quantity for making field tests of the yield of dry matter and the yield of nitrogen per acre in meadow or pasture plots.

It so happened that some of the very best plants had a tendency to long spikelets, and several of the 14 stocks which are being increased in stock-seed plots have barbed spikes, such as are shown in Plate VI, fig. 2. The three spikes on the right represent the foundation stock from which was developed by selection the new timothy represented by the three spikes on the left, which shows a tendency to branch by lengthening some of its spikelets. A distinguishing mark like this would have value in a new kind of timothy, since it would distinguish it from common timothy, which has not as yet been broken up into successful varieties. But in the end the historical method by numbers used for names may be the most practical way of keeping track of the strains and varieties of timothy, because a variety of barbed timothy could easily be broken up into strains or subvarieties, some of which would have greater value than others. Breeders are prone to breed for the distinguishing marks and to exert their energies in making the new botanical characteristics come true to type, rather than to seek first the yield per acre and quality of the grass and hay. The difficulty of planting these minute seeds in hills in the field and the gain of a year in the maturity of the plants has led to the plan of planting the seeds in greenhouse pots in winter and transplanting to the field in the spring. Since timothy is an open-pollinated species, it would seem unwise to base efforts for its improvement upon a single mother plant. Effort should be directed to finding superior individuals and mixing together their seeds for breeding purposes. To

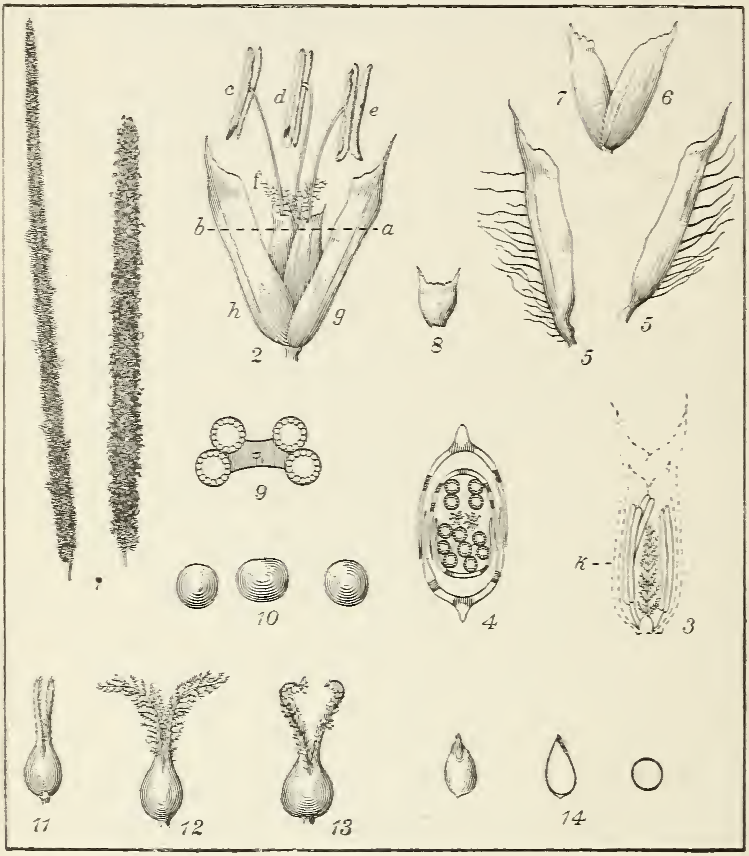


FIG. 20.—Floral organs of timothy. *1*, two types of spikes, the righthand one in bloom, the left hand one a new variety, showing extended spikes. *2*, a single flower: *h*, *g*, empty glumes; *a*, *b*, flowering glumes; *c*, *d*, *e*, anthers; *f*, stigma. *3*, longitudinal diagram of flowers showing position of organs within the unopened glumes at *k*. *4*, transverse diagram of flower. *5*, outer or empty glumes. *6*, flowering glume. *7*, palet. *8*, lodicule. *9*, transverse diagram of anther *10*, pollen grains. *11*, *12*, *13*, pistil before, at the time of, and after pollination. *14*, outer, longitudinal, and transverse appearance of seed.

increase variation, timothy seeds from widely separated sources may be mixed together and seeds from the mixed planting planted in the nursery. Or the stocks of seeds from separate sources may be grown in the nursery and the seeds of the best selected plants may then be mixed together and allowed to cross, thus giving crosses between strong parent plants. In any case these cross-bred stocks may be selected as under the plans given in the first part of this section.

BREEDING POTATOES.

Potatoes will serve as an example of a species the improved varieties of which are propagated wholly by cuttings, the seeds being used only in variety formation. The tops live only one year. The age to which a variety propagated by annually planting the root cuttings of a single seminally produced plant will live before the necessity of renewal by sexual reproduction is resorted to is not known. But since standard varieties of potatoes remain prominent for only about a third of a century, there is some reason for the belief that the varieties reach their period of old age, or senility, in that time.

Some of the many commonly grown varieties produce many seeds, but others produce very few seeds; and under some conditions most of the cultivated varieties bear very few seed balls. Doubtless those best acquainted with the formation of varieties of potatoes may have a knowledge of which varieties, or hybrids between which varieties, have proven best to use in making new sorts. There are annually many new kinds created, but only a very small part of 1 per cent of these ever reach the prominence of commercial sorts. Luther Burbank is quoted as saying that not more than one new variety of potato in five thousand should be named and disseminated.

The potato flower is quite open, and cross-pollination by hand is easily effected. The fruit, "potato ball," contains numerous seeds, each of which is capable of being developed into a new variety of potato. New varieties may be originated by planting seeds which have not resulted from crossing between varieties; but the supposition is that a larger proportion of good kinds would result were hybrid seeds from hand-pollinated flowers used.

The seeds are planted in the open field or under glass, and when several inches high the plants may be transplanted into the field, where each plant should be in a hill by itself, each having its serial number. In radical hybrids very poor seeds, and even plants which at first appear undesirable, sometimes become the foundation of superior varieties. The plants do not generally grow large the first year, and the tubers are small. By discarding all the tubers of the poorer three-fourths of the plants, only the best are retained for planting the second year. Several hills of each should be grown under proper nursery-stock numbers, so as to get averages, and when the tubers are mature most of the stocks grown this second year should be discarded. These are again planted, and those averaging poorest for the three years are discarded. Any very promising sorts are now rapidly multiplied for variety field tests. These new varieties are yearly compared with the standard sorts as to yield of tubers, cooking quality, form, size, and general appearance of tubers; where wanted for the production of starch they are tested for the percentage content of starch in the ripe tubers. Several kinds of apparatus for the determination of starch in potatoes have been devised. Other characteristics—as earliness, size of vines, and adaptability to certain soils and local conditions—are also noted. There has been very much effective work done in the breeding of potatoes by Burbank, of California; Heine, of Saxony, Germany; Archibald Finley, of Scotland, and many others. The transformation and constant improvement of this once wild American species is quite astonishing, and forms another remarkable example of what can be done by intelligent effort in plant breeding.

BREEDING APPLES.

The apple will serve as an example of an open-fertilized perennial species the varieties of which do not come true to type from seed, but are propagated mainly by grafting the buds or cuttings on other hardy stocks. While plants of this class require a number of years to bring them to the age of fruiting, and still longer to test their hardiness, quality, and yield, there is the great advantage which comes from propagating from buds or cuttings. There is not the necessity of breeding them to uniformity of type, because the cuttings and grafts, being only a part of the single seminal plant, are all true to type. This is also an excellent example of a plant which has been broken up into very many useful varieties by the discovery of superior trees which have come up accidentally, as along fence rows or about cider mills.

There is considerable variation in plants from seeds of self-fertilized apples grown in orchards where the trees are not near trees of other varieties; but much more where the trees of different sorts are close together, resulting in cross-pollination by the wind and by insects, and where the seeds are from fruits of flowers which have been cross-pollinated by hand. Many of our good varieties of apples have sprung from seedling trees produced from seeds from self-pollinated flowers or from seeds resulting from natural hybridizing in orchards where the trees of two or more varieties are adjacent. But in systematic work in apple breeding it is believed that more is accomplished with a given expenditure by artificially crossing those better varieties which combine the desired qualities, and thus producing many variable plants, any one of which proving of value may be rapidly propagated by grafting or budding for dissemination as a new variety. There is an important advantage in the systematic method of cross-pollination.

Records can be kept of the crosses made, and, plants from each cross having been tested, the results can be compared, and thus those crosses which have given the largest proportion of useful varieties can be known, so as to use them more extensively in future hybridizing.

The individual seed and the tree springing from it being the unit of the entire variety, each individual apple plant should be given a number, and notes should be recorded for each tree from its birth to its rejection, or until its selection as the mother of a variety for dissemination.

Each variety used as the parent of a hybrid may be considered as one plant, since all came from a single seed. If from Wealthy-Oldenburg hybrids made in large numbers there resulted wonderful variation with many trees producing good apples, all of which mature in autumn, we would expect further breeding of this cross to produce mainly varieties which would not keep in winter. If hybridizing Rhode Island Greening-Oldenburg produced mostly winter keepers, even though only a small percentage of good ones resulted, we should look more to this combination to produce the long-wished-for hardy varieties of winter keepers which are needed to push the winter-apple zone northward. The characteristics of individual trees of the "fraternity" group designated in this article as the "centgener" should, so far as practicable, be recorded in numerical averages, that one cross may be compared with another. Not only will our experimenters be able thus to learn which varieties are best to cross, but the more careful work will result in a better knowledge of the best ways of breeding apples.

HOW TO HYBRIDIZE APPLES.

There is such a multiplicity of conditions for which varieties of apples are desired that the work of variety formation of apples is largely creative. The Minnesota Horticultural Society offers a premium of $1,000 to the originator of an apple as hardy and productive as the Oldenburg, equal to the Wealthy in size and flavor, and to the Malinda in keeping quality. A permanent committee, with Prof. S. B. Green, of St. Anthony Park, Minn., as chairman, has charge of the awards.

Prof. N. E. Hansen, of the South Dakota Agricultural College, says:

> The Northwest at present needs varieties of applies combining the hardiness and freedom from scab of the best Russian varieties with the choice quality and long-keeping capacity of our best American winter varieties. A variety as hardy and large as Hibernal, as choice in quality as Northern Spy, and as long a keeper as Ben Davis or Romanite would be worth millions of dollars to the prairie Northwest.

Professor Hansen is crossing and hybridizing these types and other American and Russian varieties, as Siberian and hybrid Siberian crabs, large-fruited native crabs, Chinese red-flesh crabs, seedless apples, and other forms of apples from various parts of the world. He urges that an abundance of trees of a new variety should be started, that the new variety may be given a thorough trial, not only for a few winters, but until "bearing and test winters occur together," so as to thoroughly test their hardiness, and he is testing many new means of aiding the trees to endure the winters, as dwarfing, potting, grafting on hardy species, etc.

Prof. S. A. Beach, of the New York experiment station, says: "The breeding of apples in an unsystematic way is going on all over the country. I know of a rocky pasture where seeds were distributed by cows which had access to the pomace of a cider mill, and now thousands of trees are in bearing there. We have grafted about 75 selected kinds from these trees. The varieties commonly grown have mostly originated in this way, and may be looked upon as the few survivals from thousands upon thousands which have been allowed to fruit in neglected places." He has made many crosses and grown from seeds of self-bred flowers for the great apple regions of New York varieties which are superior to those now in use. His effort in his systematic crossing is "to combine features which exist in varieties which are known, but which are not combined in the way we most desire." Pure seedlings are grown "of the same parents to discover what features they may be expected to impress most persistently and firmly upon their progeny, and thus produce parents which will be most apt to transmit their characteristics with certainty." If Professor Beach succeeds in his plans he will have varieties "with attractive red fruit, ripening here in midwinter or later, approaching Ben Davis in regular bearing, vigor, and health, and considerably excelling it in quality of fruit." Looking toward this end, he is growing seedlings from the following crosses: Ben Davis-Esopus (Spitzenburg); Ben Davis-McIntosh; Ben Davis-Gravestein; Ben Davis-Green Newton. In like manner other varieties are being crossed to produce fall and winter apples which have red fruit of excellent quality and other good characteristics, as health, productiveness, etc.

Prof. John Craig, formerly of the Iowa Agricultural College, who was breeding apples extensively, said:

> (1) In order to do the work of crossing expeditiously and in a large way, it is necessary to have a quantity of pollen at hand. This, of necessity, will have to be collected from a region south or west of the point at which the work is to be done, and where the apple blooms earlier. In collecting it the blossom clusters are either picked from the branches, or a branch of considerable size is brought into a greenhouse or warm room. This is done just as the flower buds begin to open. In twenty-four to forty-eight hours the anthers will have burst, and they may then be removed with the pollen. This is quickly done by clipping them off with scissors. If a considerable quantity of pollen of a given variety is collected, care should be taken not to bottle it up closely immediately after it is gathered. Heating is likely to ensue, and the pollen may be rendered valueless. It should

be spread on sheets and dried, not to absolute dryness, but so that it will remain in powderly form, rather than adhere in pellets.

(2) Good, vigorous trees are selected. Strong blossom clusters are chosen. The outside buds are rejected, and three to four of the strongest buds near the center of the cluster are selected. In the case of large apples only two buds are chosen in a cluster. The work of emasculating should begin when the buds have fully expanded, but have not yet begun to open. The stamens may be removed by the use of a small pair of sharp-pointed forceps; I prefer these to straight or curved scissors. Care should be taken in doing this work that pollen from branches above is not transferred to the stigma of the blossoms being operated upon. The emasculated blossoms are covered with brown paper sacks. In the Eastern States, where more atmospheric humidity is present, and where there is a larger percentage of cloudy weather, it is desirable that paper sacks of a light weight should be used. The sack is attached to the twig or branch by means of a string which is tied to one edge of the sack, and is used to draw the mouth of the sack tightly together about the branch. Each cluster is then labeled with an ordinary nursery tag attached to the twig with a copper wire.

(3) The work of pollinating may be very much expedited if a variety of pollen is inclosed in a small homeopathic vial, and with it a small camel's-hair brush. In working on a large scale I find that it is much more satisfactory to, in the first place, collect an abundance of pollen and use it freely than to gather the pollen as required and apply it with any other instrument than the camel's-hair brush. Having a vial labeled and supplied with its own brush, all parts of the work can be done by the same operator, namely, the work of removing sacks, applying the pollen, and replacing the sacks.

(4) The paper sacks, if tightly tied on (which is necessary in this locality on account of the strong winds), will prevent the full development of the fruit if allowed to remain on more than ten days or two weeks after pollination. They should then be exchanged for sacks made of mosquito bar. These are cheaply made, costing about 1 cent each. They are tied on by having a running string around the mouth, which is closely drawn about the branch. The sacks protect the fruit from bird attacks, and to some extent from insects; they also prevent it from being lost if blown off by high winds.

(5) The common copper wire nursery label is used. One label is placed on each sack, and first records the name of the female and then that of the pollen-producing parent, as, for instance, "Mercer-Ben Davis, '99." The records of the seedlings may be kept by prefixing a numeral in each case and using the initial letter of each parent, as "1 M.-B. D., '99;" "2 M.-B. D., '99," etc. Each individual tree from every crossed seed planted is recorded and numbered separately.

As a rule, I do not plant the seeds of apples which are not crossbred. Occasionally a considerable quantity of seed of a special variety is planted, and in this case the trees are not recorded until they come into bearing. Then only those giving special promise are numbered.

Prof. J. L. Budd, of the Iowa Agricultural College, has made many apple hybrids, using the Russian varieties freely, and many of these are now coming into fruitage. Several of Professor Budd's students, having gained inspiration from him, are now breeding apples and other plants on an extensive scale.

Mr. C. G. Patton, of Iowa, the originator of Patton's Greening and other good seedlings, has long appreciated the possibilities in apple breeding. Luther Burbank is said to have made progress in making varieties suited to California conditions. He grafts scions of the new seedlings on standard apples, sometimes over 500 new kinds on one large tree, that all may be tried under similar conditions. Prof. S. B. Green, of the University of Minnesota, is breeding apples. He says:

> We know little about which varieties to use for superior crosses. The matter is of such immense importance that we should make very many hybrids between very many varieties.

BREEDING BLACK WALNUTS.

The black walnut serves well to illustrate the breeding of those forest and ornamental trees which are propagated by seeds. Walnut trees are grown for large logs of valuable lumber. Therefore the planter needs varieties which will make rapid growth and will mature early into trees of large size, straight, and of good form. In selecting seeds to plant, growers usually get nuts wherever they are secured with greatest ease. This leads to taking most of the seeds from heavy seed-bearing trees rather than from those trees which make a rapid and large growth of lumber. In case of this tree the nuts have some value, but in many species the seeds are of no use except to use in propagating, and if the tree bears many seeds it must do so at the expense of the production of wood.

It might seem that the breeding of walnut and other trees is impracticable because of the long time required to get results. But the time is not so long as might be supposed, as will be brought out by the following suggested plan of securing superior varieties of walnuts.

Since the pollen-bearing organs and the ovaries are in separate flowers, the flowers are often cross-pollinated from other trees, and there is considerable variation and opportunity for selection among trees from nuts of the same mother tree. Likewise, there is great variation between the plants grown from the nuts from several trees growing native in one neighborhood, and doubtless still greater among plants from mother trees found native in widely separated portions of the country.

The writer, over twenty years ago, in central Iowa, planted some acres to black walnut, and, the method of planting proving very good and the distance apart about right, the suggestions here are in part based upon that experience. The nuts were from various large and small native trees along a neighboring stream. They were gathered when sufficiently ripe to be easily shaken to the earth, and were at once placed in trenches 6 inches deep and 2 feet wide, running down a slight incline in the shade of a grove. Moist straw or leaves were placed over the nuts, from which the hulls had not been removed. The nuts were thus kept moist all winter, that they might be cracked by freezing. In the spring the fall-plowed land was marked off each way with a corn marker, making cross marks nearly 4 feet apart each way. The nuts were planted in each hill of every third row, thus placing them 4 feet apart in rows 12 feet apart. Some nuts will lie in the ground one or two years before germinating, but by planting three in a hill and thinning to the one strongest plant a full stand can be secured. Two rows of corn or potatoes were grown between each two rows of trees for three or four years, thus giving a partial crop to in part repay the thorough culture and weed killing. Thus cultivated, the trees grew very rapidly, some bearing nuts in ten years. In the twelfth year the poorer plants were removed, yielding 125 posts per acre, worth $12.50, and sufficient fuel to pay for thinning and making the posts.

If a plan such as the above is adopted and the nuts from the various native trees are planted separately, by the twelfth year choice can be made between them as to their value as mother trees, and nuts from the largest well-formed trees can be chosen for further planting. The seeds of two or more of the best of these trees may be planted in alternate rows, so as to allow of natural hybridizing in the next generation.

Cross-pollinating may also be done by hand among the best specimens. Those between native stocks brought from widely separated regions would be most likely to vary, and thus give opportunity to select useful new forms.

But even this need not be the limit of breeding operations. Luther Burbank's cross between the Eastern black walnut (*Juglans nigra*) and the California walnut (*J. californica*) illustrates the fact that the species of our forest and nut-bearing trees will in some cases hybridize, and these radical crosses made in immense numbers, followed by rigid and extensive selections, are sure to result in the production of useful new hybrids quite as marked as ordinary species. The trees in the grove mentioned above are now about 40 feet high. They are proving a profitable investment, and breeding them as suggested above could have been done at slight additional expense.

BREEDING FLAX.

In flax we have an example of the breeding of a species yielding two distinct valuable products—seed and fiber. So far as the writer knows, there has been no attempt, except in the Minnesota experiment station, to systematically breed varieties of flax for seed and for fiber. For this State the common blue-flowered flax has been found best. This flax has been imported from Russia at various times during the past thirty or more years, and the presumption is that the flax generally grown in large quantities for seed in Minnesota and surrounding States is the variety which has been long in use in Russia. While White Dutch and other kinds of flax have been tested for raising crops of seed, the Russian variety retains the supremacy, and is best in this climate for fiber also.

The flax grown for fiber in the British Islands and on the western portion of the European continent is nearly all of Russian origin.

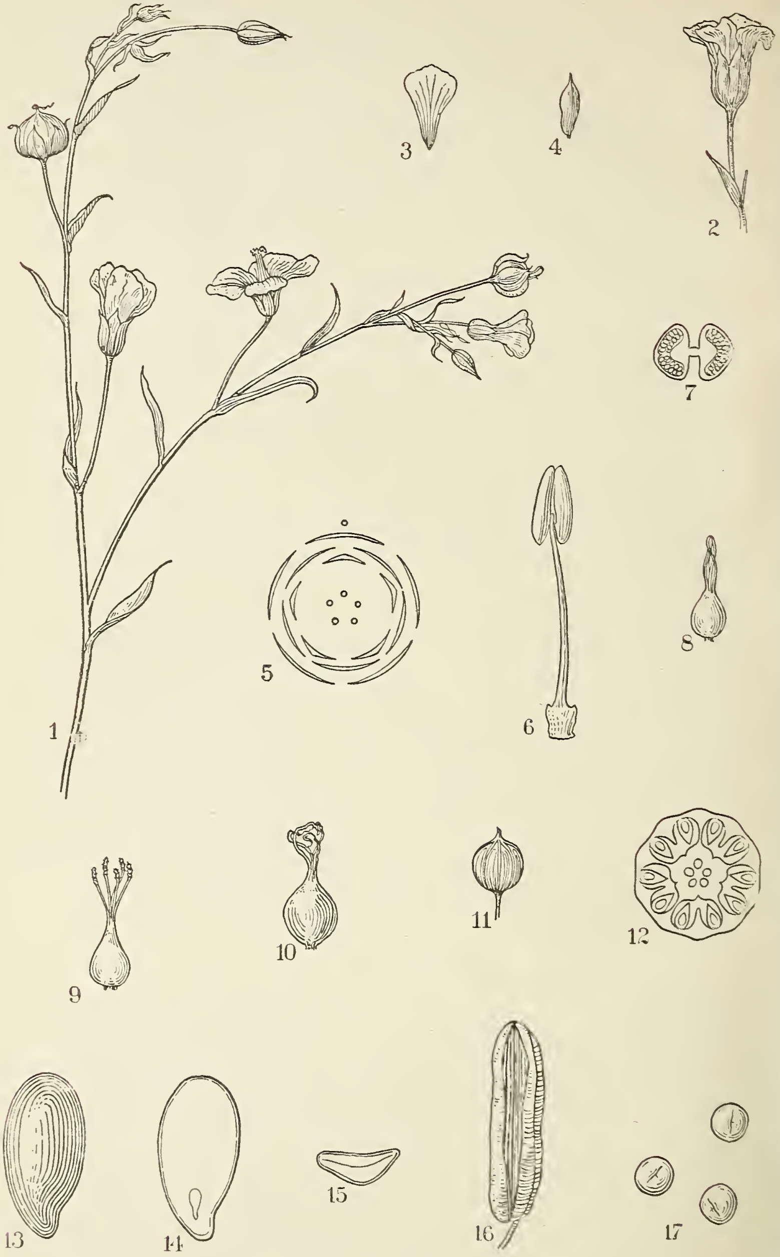


FIG. 21.—Flowers of flax. *1*, branch, with flowers and fruit; *2*, flower half open; *3*, petal; *4*, sepal; *5*, diagrammatic section of flower; *6*, anther, with filament; *7*, transverse section of anther; *8*, *9*, *10*, pistils, before, at time of, and just after pollination; *11*, ripe fruit; *12*, diagrammatic transverse section of fruit; *13*, seed; *14*, *15*, longitudinal and transverse sections of seed; *16*, anther; *17*, pollen grains.

The farmers of Ireland, Scotland, Holland, and Belgium import their seed from the vicinity of Riga, Russia, and after growing two crops of fiber they import fresh seed. Americans who grow flax for fine fiber have also imported part of their seed from Riga and part from Holland. There is apparently only one variety of this Russian seed generally recognized commercially. At the Minnesota experiment station, Minnesota or Dakota grown flax has been repeatedly grown beside that from the Russian seed recently imported. The two were apparently identical, whether sown thinly for crops of seed or thickly for crops of fine fiber. It is reported that in some Russian districts are to be found varieties better suited for growing fiber in dry climates, and an effort is being made to secure them.

For the States of the middle Northwest two kinds are wanted—one to sow at the rate of 3 pecks, or less, of seed per acre for large crops of seed; the other to sow at the rate of 2 bushels or more of seed per acre to grow large crops of long, fine fiber. If a number of such fiber varieties were developed here some of them might be found especially suited to growing flax fiber in Ireland, Holland, and Belgium, and in other countries which now purchase their flaxseed from other countries; arrangements have been made for testing some of the new varieties already formed in the European districts which import the flaxseed for their fiber crops.

The plan developed for breeding flax may be briefly stated, as follows:

1. Secure various stocks or varieties of flaxseed, and, having tested them so as to choose one or more of the best, sow broadcast at the rate of not over 1 bushel per acre in plots of at least one-tenth of an acre.

2. With great diligence seek among the plants growing in the field plot a number of plants which are strong, tall-growing, or medium tall fiber plants, and a like number of ordinary height which bear heavily of seed.

3. From each of these plant a centgener, placing three seeds in hills 5 or 6 inches apart each way, and when several inches high thinning to one plant in the hill.

4. When mature, take notes on each centgener on a blank form, with headings somewhat as follows: Centgener No.; Height; Strength; Average yield; Tendency to tiller; Tendency to branch; Evenness of ripening. Doubtless the content of oil and of nitrogen in the seed can be increased, and also the fineness and the quantity per acre of the fiber, together with the ability to stand erect, though these latter qualities, being somewhat antagonistic, are blended in one variety with difficulty.

5. Discard 90 to 95 per cent of the plants, and take full notes on the remaining plants on a blank form like the following:

FLAX.

Nursery No		181
Type		Fiber.
Date when ripe		Aug. 15
Height	inches	40
Number of tillers		1
Number of branches		5
Number of bolls		6
Evenness of ripening	per cent	90
Size of seeds	do	97
Grade of seed	do	95
Gross yield of seed	grams	22.5
Net yield of seed	do	16.4

6. From among each of the best centgeners of each type choose a few of the best plants for mothers of centgeners the second year, and continue year after year recording, compiling, and averaging the facts.

7. When any stock has shown a superior habit of growth, yield, and quality, multiply it rapidly and test it in the field, and, if a fiber kind, test it also in the factory or laboratory for yield and quality of fiber in comparison with standard varieties. Laboratory methods are being developed for testing the strength and fineness of the fiber and for determining its percentage of the crop, so as to determine the yield of fiber.

8. It may not be wise to limit the parentage of a new flax to a single mother plant, as this is an open-pollinated species, but the seeds from three or more centgeners may be mixed together in attempting to make a new variety.

9. Stocks once started in the nursery will serve as excellent parents to use in creating new qualities by hybridizing.

10. Hybrid stocks may be grown in bulk for a few years, that variation may fully develop, the selection then being carried on as under paragraphs 2 to 8, inclusive.

11. Two varieties may be hybridized by mixing the seed and sowing for two or three years in a plot or field, from which superior mother plants may then be chosen, as already described.

12. New hybrid varieties should not be distributed to growers until they have been tested several years in uniform test plots.

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